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II. STIMULATORY ACTION

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BORDEAUX MIXTURE. II. STIMULATORY ACTION.

By O. BUTLER.

Multis matribus creatum.

The physiological response of plants following spraying with Bordeaux mixture has, even more than the toxic action of the fungicide, been made the matter of repeated study; but opinions differ, divergent views are held, in other words necessary facts are required to complete existing knowledge and further study may be usefully undertaken. A review of the literature will permit us to estimate the work already accomplished and lay the foundations for the present studies.

I.

Following the introduction of Bordeaux mixture in 1885 it was noticed that the fungicide had an effect upon the sprayed plant which was independent of the protection afforded from parasitic fungi. Rumm (1) tells us that spraying with Bordeaux mixture increases the general vigor and health of the grape and advances the time of flowering and maturation of the fruit. The leaves of sprayed plants are greener than those of non-sprayed plants and they are also thicker though not exceptionally so. The chloroplasts in sprayed leaves are smaller but more numerous than those in non-sprayed leaves. The author, unable to detect any copper in sprayed leaves, believes that the action of Bordeaux mixture is due to the metal acting chemotactically through the epidermis.

Frank and Krüger (2) sprayed Early Rose and Furst von Luppe, a late variety of potato, with Bordeaux mixture and milk of lime, the former being used in both light (50 cc. per plant) and heavy (160 cc. per plant) applications. Sprayed leaves were either thicker than or of the same thickness as non-sprayed leaves, but never thinner. The increase in thickness was due to a reduction in size of the air cavities in the spongy parenchyma brought about not by an increase in the number of cells but by a slight and general increase in the size of the walls of all the cells. Chlorophyll was more abundant in the plants sprayed with Bordeaux mixture, the effect being more marked in the case of the heavily sprayed plants, than in those sprayed with milk of lime, or the witnesses. At eventide the reaction for starch was the same in all leaves whether sprayed or not, but early in the morning marked differences were observed. In the leaves of the witness plants starch would be absent; in the plants sprayed with milk of lime starch was only present in small amount in the palisade tissue and abutting spongy parenchyma cells; in the plants sprayed with Bordeaux mixture starch was present in abundance though in lesser amount near the lower than the upper epidermis. Spraying with Bordeaux mixture also increased transpiration but the milk of lime gave contradictory results: transpiration was increased in the case of Furst von Luppe, decreased in the case of Early Rose.

As regards the cause of the stimulatory action of Bordeaux mixture the authors do not take a very definite position. They are, however, of the opinion that it is not a soluble constituent of the mixture that produces the effect. This conclusion is based on the observation that spores of *Phoma betae* and *Plasmopara viticola* show signs of death when placed in Bordeaux mixture but are not injuriously affected when placed in the filtrate from this mixture.

Zucker (3) in his experiments employed a 3 per cent Bordeaux mixture containing 3 per cent cane sugar in which copper sulphate and quick lime were used in the ratio of 1: 0.53. Milk of lime containing 2 per cent calcium oxide was also used. A number of plants were studied and observations were made six to eight weeks after the plants had been sprayed. The author studied the effect of spraying on the anatomical structure of the leaves, the relative chlorophyll content, rate of assimilation and transpiration. The leaves were also analyzed for presence of copper by the electrolytic method, but none was found. In estimating the effect of spraying on the development of chlorophyll the author used Hansen's method; assimilatory activity was determined by Sach's method and transpiration after the methods of Unger and Pfeffer. The results secured by Zucker are indicated in Table I and

TABLE I.—*Effect of spraying with Bordeaux mixture and milk of lime on the development of chlorophyll and rates of assimilation and transpiration.*

Plant used.	Effect of spraying on					
	Chlorophyll develop.		Starch formation.		Transpiration.	
	Milk of lime used.	Bordeaux mixture used.	Milk of lime used.	Bordeaux mixture used.	Milk of lime used.	Bordeaux mixture used.
Nicotiana collosea	<	<	=	<	<	<
Coffea arabica	=	<<	<	<	>	<
Ricinus communis	=	<	<	<	>	<
Coleus hybrida	=	=	=	<	<	<
Pereskia aculeata	=	=	<	<	=	<
Begonia lebrina	=	<	=	<	<	<
Eucalytus tereticornis	=	<<	=	<	>	<
Melaleuca alba	=	<<	=	<	>	<
Tydaea grandiflora	=	<<	=	<	>	<
Cestrum roseum	=	<<	=	<	>	<
Aralia pentophylla	=	<<	=	<	>	<
Juniperus bermudiana	=	<	=	<	>	<

Legend:
= equal to witness
< greater than witness
> less than witness

show that spraying with Bordeaux mixture caused in all cases increased development of chlorophyll, a more abundant deposit of starch, and greater transpiration; while milk of lime was inactive, or caused either a negative or positive response depending upon the plant studied. Chlorophyll development was increased in the case of *Nicotiana collosea* but unaffected in the case of all the other plants studied; starch formation was increased in the case of

three plants but unaffected in the case of the remaining nine; transpiration was usually less than that of the witness plants.

The author believes that the stimulatory action of Bordeaux mixture is an electric one. He points out that etiolated plants become green under the influence of an electric current and that spraying has a similar effect. The transpiration current in plants is electro-positive while copper is electro-negative, hence the current set up between the two gives rise to the stimulus observed.

Aderhold (4), believing that the stimulatory action of Bordeaux mixture might be due to the lime salts it contains, or to the presence of ferrous sulphate, undertook the following experiments. He grew *Phaseolus multiflorus* in water cultures (Sach's solution) until the plants were well developed when they were transferred to a lime free nutritive solution. One half the plants were sprayed with a mixture containing 2.64 per cent calcium hydrate and 1.75 per cent calcium sulphate, while the remaining half were kept as a witness. All the plants were stood in the open air so that rain and dew could fall freely upon them, precautions being taken, however, to prevent contamination of the culture media. It appeared at first as if the calcium salts had a stimulatory action, but the effect produced was not lasting and both the sprayed and unsprayed plants died at the same time.

In another experiment a field of potatoes was divided into five plots and sprayed as follows: Plot 1, with a 2 per cent Bordeaux mixture 1: 1.5; plot 2, with a mixture made with 2.64 per cent calcium hydrate and 1.75 per cent calcium sulphate; plot 3, with a 1.75 per cent calcium sulphate wash, and plot 4 with eau celeste. Toward the close of the growing season stimulation by Bordeaux mixture was apparent, but the rate of transpiration of the plants in all the plots was the same. The leaves of the plants growing in plots 1 and 2 contained more starch than those of the plants in the other plots. The author next studied the effect of iron as a stimulatory agent. He divided a field of beans into eight plots* which were sprayed as follows: Plot 1, witness; plot 2, 1 per cent Bordeaux 1: 1 iron free made with distilled water; plot 3, 0.75 per cent Bordeaux mixture 1: 1.33 containing 0.25 per cent ferrous sulphate, and made with commercially pure salts dissolved in tap water; plot 4, 1 per cent Bordeaux mixture 1 : 1 made with commercially pure salts dissolved in tap water; plot 5, 0.95 per cent Bordeaux mixture 1 : 1 containing .05 per cent ferrous sulphate, made with tap water; plot 6, 0.95 per cent Bordeaux mixture 1: 1.05 containing .05 per cent ferrous sulphate and made with distilled water; plot 7, a mixture made like a 1 per cent Bordeaux mixture 1 : 1 but in which ferrous sulphate was substituted for cupric sulphate, distilled water being used in its preparation; and plot 8, witness.

The leaves of the plants in plots 5 and 6 were markedly greener than those taken from plants growing in plots 1 and 2, while the leaves of the plants in plots 4 and 5 occupied, as it were, an intermediary position. The mixture used on plot 7 was injurious, hence the author concluded that too much iron may be harmful. Plants from all the plots were cut and placed in water in a room and data was taken on the rate of withering, which was as follows (increasing scale): plots 8, 7, 3, 1, 2, 4, 5, 6.

*Owing to an error at time of planting a different variety of bean was used in plots 7 and 8.

The author also studied rate of carbohydrate assimilation using the iodine test, and was able to separate the plants from the several plots into groups, as a glance at Table II will show.

TABLE II.—*Effect of the presence of iron in Bordeaux mixture on the Carbohydrate synthesis of potato leaves.*

Method of treatment.	No. leaves tested.	Intensity of coloration obtained.			
		Faint blue.	Moderately deep blue.	Deep blue.	Very deep blue.
		Per cent.	Per cent.	Per cent.	Per cent.
Witness	16	....	100	....	....
1% Bordeaux mixture iron free	14	21.4	71.4	7.14	....
1% Bordeaux mixture containing 0.25% ferrous sulphate	12	....	58.1	41.6	....
1% Bordeaux mixture technically pure	16	....	87.5	12.5	....
1% Bordeaux mixture containing .05% ferrous sulphate, technically pure salts used	19	....	47.3	36.8	15.8
1% Bordeaux mixture containing 5% ferrous sulphate	19	....	31.5	15.8	52.6
Ferrous sulphate mixture	16	....	31.2	25.0	43.7
Witness	16	....	37.5	31.2	31.2

Aderhold's conclusion is that the stimulatory action of Bordeaux mixture is due to the presence of iron.

Bayer (5) tells us that the stimulatory action of Bordeaux mixture may be general over the entire sprayed leaf or only localized in those portions immediately covered by the mixture. Some plants, such as the red orrache or notch-weed possessing red cell-sap, become green when sprayed, an indication that the sap which was acid has been neutralized or rendered alkaline. Copper hydroxide alone stimulates *Phaseolus vulgaris* and *Vitis vinifera* to the same extent as Bordeaux mixture. *Pisum sativum* and *Solanum tuberosum* plants show a greater development of chloroplasts and an increased starch content when sprayed, the results obtained with the potato being the more striking. The leucoplasts in the epidermal cells of a good many plants are transformed as a result of spraying with Bordeaux mixture into chloroplasts. Transpiration is not always increased. In the case of *P. vulgaris* and *V. vinifera* spraying does not affect this function, but in the case of *S. tuberosum* it is increased slightly. In *P. vulgaris* and *V. vinifera* the palisade tissue becomes narrower and in the case of the former, also longer. In *P. vulgaris* the ratio of the palisade cells in sprayed plants to those in non-sprayed plants is as 1: 0.8. In *V. vinifera* there are three to four palisade cells to every epidermal cell in sprayed plants and two to three in the witness plants. The foliage of sprayed plants remains green longer than that of non-sprayed plants.

According to Porchet (6) Bordeaux mixture heightens the color of the foliage of the following plants: *Vitis vinifera, Solanum lycopersicum, Chrysanthemum,* but does not modify the color of the foliage of the following plants: *Ribes rubrum, R. grossularia, Rubus Idaeus, Pisum sativum, Phaseolus vulgaris, Vicia faba, Spinacea oleracea, Chicorium itybus, Iris germanica.*

The author believes that foliage sprayed with a copper fungicide absorbs traces of copper. He was unable, however, to reach this conclusion by direct experimentation since copper was not detected in the leaves except when it had been absorbed through the roots. The most noticeable result was obtained by growing *Vitis vinifera* cuttings in peat to which copper sulphate had been added. Stimulation, *i.e.*, darker colored foliage, earlier and more vigorous growth, later leaf-fall, occurred when the concentration of copper sulphate employed was 0.01 per cent. The aerial portions of plants growing in this concentration of copper sulphate contained copper in sufficient quantity to be detected by electrolysis.

Schrander (7) tells us that the stimulatory action of Bordeaux mixture is evidenced by the leaves becoming thicker, larger and darker green. Spraying lowers the rate of transpiration, increases carbohydrate synthesis, and prolongs the growing season two weeks.

The author sprayed one-half of the leaves of several kinds of plants with Bordeaux mixture, a mixture made from milk of lime and calcium sulphate alone and the same mixture with the addition of a blue or a red pigment. The order of effectiveness as stimulants of the several mixtures was (decreasing order) Bordeaux mixture, blue mixture, red mixture, white mixture. During clear, bright weather, sprayed vitis, phaseolus, and sambucus leaves showed a deeper coloration than non-sprayed leaves, but leaves of these same plants sprayed during cloudy weather did not become darker green than non-sprayed leaves.

In an experiment with beans grown in cold frames marked results were secured. In one frame (No. 1) the plants themselves were sprayed; in another (frame No. 2) the sash was sprayed, and in another (frame No. 3) neither the plants nor the sash were sprayed. The plants in frame No. 2 grew vigorously and possessed dark green foliage; the plants in frame No. 1 also grew vigorously but their leaves, while smaller than those produced by the plants in frame No. 2, were deeper green. The plants in all three frames bloomed at the same time, but the witnesses were the first to mature.

In another experiment strong potted plants of *Vitis vinifera* were divided into two equal sets, one of which was placed in the shade, the other in direct sunlight. One-half of each of the leaves of all the plants was then sprayed with Bordeaux mixture. In the case of the plants in sunlight the sprayed halves became greener than the non-sprayed halves, whereas in the case of the plants in shade the spraying was without effect.

The upper surface of leaves of *V. vinifera* were sprayed with Bordeaux mixture and the plants placed in strong sunlight for several days. The leaves were then examined and found to contain more starch than non-sprayed leaves similarly exposed. In another experiment the under surface of *V. vinifera* leaves was sprayed, but no increased starch formation or heightened color followed the treatment until the normal position of the leaves was reversed.

Thin white paper placed over leaves of *Lappa*, *V. vinifera* and *Phaseolus vulgaris*, the plants being grown in shade and sunlight, produced an effect similar to spraying with Bordeaux mixture.

According to Schrander the stimulatory action of Bordeaux mixture is due to the shadow cast by the mixture.

In 1905 Ewert (8) published a study on the relation of light to Bordeaux mixture stimulation, and the effect of composition of the mixture on stimulation, and sought to further elucidate the nature of the physiological responses produced by the wash. In the experiments dealing with the effect of light and composition of the wash on Bordeaux mixture stimulation, the author used potatoes and beans which were grown in pots in which the soil moisture content was kept constant, but in some of the other experiments the grapevine was also used.

Experiments on the Effect of Light and Composition of the Wash on Bordeaux Mixture Stimulation.

Experiment 1. In this experiment one-half of a number of potato plants were sprayed four times with 1 per cent Bordeaux mixture 1:1 containing 0.0016 per cent ferric oxide. The plants sprayed were divided into two series: one series was left exposed to full light together with an equal number of non-sprayed plants, while the other together with the remaining half of the non-sprayed plants was placed under a dark green shade intended to simulate the light conditions prevailing under trees. The light intensity beneath the screen was $\frac{\text{full exposure}}{\text{green shade}} : \frac{1}{0.05}$, while under trees it was found to be between $\frac{1}{0.33}$ and $\frac{1}{0.66}$; in other words the plants were grown under heavy shade. During the first few weeks the Bordeaux mixture had no effect on the plants growing in full light, but materially injured those growing in shade, the plants losing one third of their leaves. About one month after the experiment began the sprayed plants in full light contained more starch than the witnesses. At the end of two and one-half months the sprayed plants growing in the shade were dead, while their witnesses were healthy and growing. In contradistinction to the sprayed plants in shade, the sprayed plants growing in full light showed only a few yellow leaves, whereas the witnesses were very yellow often to the extent of one-half the plant. The conclusions to be drawn from the experiment may be readily gathered from Table III.

TABLE III.—*Effect of spraying potatoes with 1 per cent Bordeaux mixture 1:1 on yield, transpiration and production of starch.*

Method of treatment.	Number of plants.	Plants in full light.			Plants in shade.		
		Transpiration.	Dry weight tubers.	Starch dry basis.	Transpiration.	Dry weight tubers.	Starch dry basis.
		Gms.	Gms.	Per cent.	Gms.	Gms.	Per cent.
Witness.....	6	194,165	641.0	66.70	24,380	6.9	36.69
Sprayed.....	6	175,610	743.0	62.53	23,030	2.27	41.10

Experiment 2. Potatoes were grown in full light and under the shade of apple trees. Shade was found to affect deleteriously tuber development (as

in the previous experiment), nevertheless the sprayed plants both in full light and shade gave higher yields than the witnesses.

Experiment 3. In this experiment both the effect of shade and composition of the wash were studied. The plants used (potatoes) were divided into three series. In series I the plants were exposed to full light; in series II they were placed beneath gauze (ratio: $\frac{\text{full exposure}}{\text{gauze}} = 1 : 0.675$); and in series III they were placed beneath linen cloth (ratio: $\frac{\text{full exposure}}{\text{linen}} = 1 : 0.350$). Half the plants in each series, except as noted below for series I, were sprayed with 1 per cent Bordeaux mixture alkaline to phenolphthalein and containing 0.05 per cent ferrous sulphate, the other half served as witnesses. In series I the plants were divided into three lots; one lot was sprayed with the 1 per cent Bordeaux mixture above described, another with 1 per cent Bordeaux mixture alkaline to phenolphthalein and iron free, while the plants in the remaining lot were left unsprayed.

As will be seen from the data presented in Table IV, the plants in full light

TABLE IV.—*Effect of light intensity and composition of Bordeaux mixture on yield of potatoes.*

Method of treatment.	Number of plants.	Plants in full light.		Plants beneath gauze.		Plants beneath linen.	
		Dry weight tubers.	Starch dry basis.	Dry weight tubers.	Starch dry basis.	Dry weight tubers.	Starch dry basis.
		Gms.	Per cent.	Gms.	Per cent.	Gms.	Per cent.
Witness.....	6	101.10	62.87	46.69	29.27	18.28	9.76
Bordeaux mixture free from iron..	6	82.68	49.64	37.13	20.60	15.84	8.29
Bordeaux mixture plus iron.....	6	85.36	53.79	.....	.....	.....	....

produced the largest crop, the yields obtained being in the case of all three series in decreasing order, witnesses, Bordeaux mixture plus iron, Bordeaux mixture iron free.

The plants in shade died down about 14 days later than those exposed to light. The leaves of the sprayed plants were greener than those of the witness plants even under conditions of shade, and their respiratory activity was a little greater. In the case of the sprayed leaves the starch produced was not all translocated during the night; forty-eight hours were required for its complete removal.

Experiment 4. The results obtained in experiment 3 were confirmed.

Experiment 5. In this experiment the author used Kaiser Wilhelm bush beans growing in full light, which he sprayed with the 1 per cent Bordeaux mixtures used in experiment 3, and 2 per cent milk of lime.

The plants sprayed with milk of lime were the most vigorous, then came in order those sprayed with Bordeaux mixture containing iron and iron free Bordeaux mixture. The witnesses matured first. Inhibition of starch trans-

location was in decreasing order: milk of lime, Bordeaux mixture containing iron, iron free Bordeaux mixture, witnesses.

Effect of Shade and of Bordeaux Mixture on Respiration.

In the studies on respiration Detmer's apparatus was used. Potatoes sprayed with 1 per cent Bordeaux mixture containing iron and iron free showed on the average a slight decrease in respiration compared with the non-sprayed plants though fluctuations occurred. Shading reduced respiration. Spraying with 4 per cent Bordeaux mixture noticeably decreased respiration in one instance, while in another a less marked effect was produced.

Effect of Spraying with Bordeaux Mixture on Translocation of Starch.

Leaves of which only one-half the blade was sprayed always contained more starch in the sprayed halves, the difference being more noticeable when 4 per cent Bordeaux mixture was used than when a 1 per cent wash was employed. Results similar to those secured with Bordeaux mixtures were obtained when milk of lime was applied. A slow removal of the products of assimilation was correlated with a deepening of the color of the leaves.

Effect of Chemical Constituents of Bordeaux Mixture on Diastase and Chlorophyll.

The activity of diastase was markedly reduced by Bordeaux mixture, cupric sulphate, cupric acetate, cupric hydroxide, less markedly by ferrous sulphate, ferrous sulphate and milk of lime wash, and not reduced by calcium sulphate. An alcoholic solution of chlorophyll exposed to the sun was bleached rapidly, but the addition of traces of copper delayed the change.

Ruhland (9) immersed leaves and fruit in water and determined the amount and proximate nature of the substances entering into solution, studied the effect of plant juices and excreta on the solubility of cupric hydroxide, and made a series of experiments in an effort to determine whether the stimulation of Bordeaux mixture was due to copper or to the iron which is commonly found as an impurity in technical copper sulphate. The latter experiments interest us more particularly.

Runner beans were grown in water cultures free from iron until they had become chlorotic when they were treated as follows:

Series I. One-half of each of all the leaves of all the plants was sprayed with a wash made with pure neutral cupric hydroxide in sufficient quantity to give the copper equivalent of a 2 per cent Bordeaux mixture;

Series II. One-half of each of all the leaves of all the plants was sprayed with ferric chloride (German pharmacopoea formula, 3 drops in 250 cc. water);

Series III. About 2 grams of cupric hydroxide were added to the nutritive solution;

Series IV. A few drops of ferric chloride were added to the nutritive solution.

At the end of ten days the sprayed halves of the leaves of the plants in series II were normal, but the color of the unsprayed halves was unchanged; the plants in series 4 were almost normal, while those in series 1 and 3 remained unaffected.

The experiment above mentioned was repeated with bush beans and analogous results obtained.

In 1912 Ewert (10) published a second paper on the effect produced by spraying plants with alkaline Bordeaux mixtures of various strengths. He used in his experiments potatoes, radishes, dwarf beans, *Oxalis esculenta*, *Stachys tuberifera*, red and white currants, and gooseberries, and the results obtained with these several plants were briefly as follows:

Potatoes. The potatoes were grown in pots in which the soil moisture was kept at 60 per cent of saturation. The sprayed plants were wetted at frequent intervals during the course of an experiment until injury supervened, when the treatment was discontinued or given less frequently. In 1905 the author obtained the results indicated in Table V. The experiments with 2 per

TABLE V.—*Effect of different strengths of Bordeaux mixture on weight of crop harvested.*

Strength of Bordeaux mixture used.	Weight of potatoes harvested.
	Relative numbers.
Witness	100
1 per cent Bordeaux mixture	105
2 " " " "	93.4
3 " " " "	91.4
4 " " " "	81.9

cent, 3 per cent, and 4 per cent Bordeaux mixtures were all made with carefully selected Paterson tubers, but in the case of the experiment with 1 per cent Bordeaux mixture a different variety was used and no particular care was given to the selection of the tubers. In an experiment made during 1906, spraying with 1 per cent, 2 per cent and 4 per cent Bordeaux mixtures decreased the yield; while in 1907 out of two experiments with 1 per cent Bordeaux mixture one gave an increased and the other a decreased yield. In 1908 two experiments were performed, one with 1 per cent Bordeaux mixture and the other with 4 per cent Bordeaux mixture, and a decreased yield was obtained in both instances. In 1911 potatoes were sprayed with 4 per cent Bordeaux mixture and the yield was again decreased. The spraying experiments with potatoes indicate, therefore, that 1 per cent Bordeaux mixture is not strong enough to have any noticeably depressant action, but that stronger mixtures are unquestionably injurious.

Radishes. In 1905 radishes were planted in pots of suitable size to hold fifteen plants each. When the plants were large enough the pots were divided into three series of three each. One series was sprayed with 2 per cent Bordeaux mixture, the other with 4 per cent Bordeaux mixture, and the remaining one was left as witness. For the first five days following the setting up of the experiment the sprayed plants were wetted daily with water, but thereafter only twice a week since constant humecting was causing spray injury. It was noticed that on hot sunny days the sprayed plants wilted less than the witnesses. The results of the experiment are summarized in Table VI. The figures given in the table show that the depressant action of the Bordeaux mixture was marked.

TABLE VI.—*Effect of spraying with Bordeaux mixture on the growth of radishes.*

Method of treatment.	Green weight.		Dry weight.	
	Leaves.	Roots.	Leaves.	Roots.
	Gms.	Gms.	Gms.	Gms.
Witness 1	143.6	73.0	31.1	13.2
Witness 2	151.6	91.6	31.3	15.9
2 per cent Bordeaux mixture	123.0	50.6	27.9	9.6
4 per cent Bordeaux mixture	129.6	47.0	31.3	9.1

In 1908 spraying with 4 per cent Bordeaux mixture gave results in agreement with those obtained in 1905.

Beans. In 1905 Ewert made an experiment to ascertain the effect of shading on the general development of Non Plus Ultra beans, the plants being grown in pots in which the soil moisture was kept at 50 per cent of saturation. The beans grown in the shade, that is, beneath a gauze covering stretched over framework were heavier both in green and dry weights than the non-shaded plants. In another experiment besides the influence of shade, the author also tested the action of 2 per cent and 4 per cent Bordeaux mixtures. Shading again proved beneficial. In the case of the sprayed plants an increased yield was obtained with 2 per cent Bordeaux mixture, but the 4 per cent wash had a depressing action. In 1906 further experiments were made. In one experiment shading and 2 per cent Bordeaux mixture gave as a whole better results than the witnesses, though the difference was not as marked in the case of the latter. In another experiment shading and 4 per cent Bordeaux mixture were tried. The witnesses gave the highest yield. In a third experiment the Grosse and Kleine Häfen varieties were used. In the case of the former shading proved most beneficial, 4 per cent Bordeaux mixture following next, if we take into consideration pod production, while the witnesses gave the largest growth, and the sprayed plants the least. In the case of the Kleine Häfen 2 per cent Bordeaux mixture gave the best results.

Oxalis esculenta and *Stactys tuberifera.* Since, in the case of these plants, only the effect of shade was tested it will be unnecessary for us to consider the results obtained.

Currants. In his experiments with currants the author used varieties susceptible to and resistant to *Pseudopeziza ribes.* In one experiment (1907) susceptible and resistant currants sprayed with 1 per cent and 4 per cent Bordeaux mixtures produced sweeter fruit than the witness plants. In another experiment plants of a red variety were sprayed, one set twice, and the other several times during the season, and an increase of sugar was obtained. In yet another experiment in which plants of a white susceptible variety were used spraying with 1 per cent and 4 per cent Bordeaux mixture increased the sugar content of the fruit, though the plants sprayed with the former mixture gave the higher yield.

In experiments made during the year 1908 the author found that spraying once a week increased the per cent of sugar present unmistakably though the

weight of the berries was decreased as also the number of seeds. He also found that 4 per cent Bordeaux mixture sprayed on slightly sun-scalded leaves proved very beneficial.

In 1909 the author sprayed the Rote Holländische with 4 per cent Bordeaux mixture, care being taken to keep the berries from being touched. The sprayed plants contained slightly less sugar and were less acid than the witnesses. The reverse experiment, i.e., spraying the fruit and not the leaves, was then tried on the Victoria (one plant) and the Rote Kaiserliche. In this case the sugar content of the berries was increased and the acidity reduced about 0.8 per cent. The berries also colored and ripened earlier than the fruit on the witness plants. Two experiments with 2 per cent Bordeaux mixture were tried. In one an increase of sugar and acidity occurred, in the other a decrease in sugar and acidity.

In 1910 the berries of the Weissen Holländischen were sprayed with 4 per cent Bordeaux mixture and an increase in per cent of sugar was obtained. Roten Holländischen were sprayed with 2 per cent Bordeaux mixture, one set of plants twice, the other only once. An increase of sugar occurred in the first instance, but not in the second.

In 1911 several experiments were performed. In one Rote Holländischen were sprayed with 4 per cent Bordeaux mixture, as follows: 1. Fruit only; 2. Leaves only; 3. Leaves and fruit. When only the fruit was sprayed an increase of sugar was obtained; when the leaves and fruit were sprayed an increase was also obtained but it was not quite so large; when the leaves only were sprayed there was less sugar formed than in the witnesses. In another experiment in which 1 per cent Bordeaux mixture was used, the greatest increase of sugar occurred when only the berries were sprayed, and the fruit of the witness plants was the poorest. In yet another experiment the author found that the berries of Weissen Holländischen sprayed with 1 per cent Bordeaux mixture were richer in sugar than the berries of the witness plants.

Gooseberries. Spraying the fruit with 4 per cent Bordeaux mixture increased in most instances the per cent of sugar formed.

Chuard and Porchet (11) tell us that spraying with Bordeaux mixture lengthens the growing season. Sprayed leaves are not only darker than non-sprayed leaves, but leaf-fall once begun proceeds unusually slowly. They used in their experiment gooseberries and currants. The plants were carefully chosen for uniformity, and were divided into two lots, one of which was sprayed twice, while the other was left unsprayed. The fruit was gathered at different periods of vegetation, very carefully sampled, and analyzed for sugar and acidity. The results are given in Table VII. As will be gathered from the table, no change in acidity occurred in the gooseberries and only a slight increase, (3 cc. normal caustic soda), was found in the currants. Total sugar in the gooseberries and currants was slightly greater in the sprayed plants, 0.51 per cent in the former and 1.14 per cent in the latter. The authors point out that when sprayed leaves are carefully washed with hydrochloric acid, the chlorophyll extracts of sprayed and non-sprayed foliage are identical. They note that the chlorophyll of gooseberry leaves assumes the dark green coloration characteristic of the extracts of sprayed leaves even in the presence of 0.00025 per cent sulphate of copper.

TABLE VII.—*Effect of spraying with Bordeaux mixture on the maturation of gooseberries and currants.*

A. Gooseberries.

Substance determined.	Plants.	Date of sampling.					
		9 May.	22 May.	6 June.	20 June.	3 July.	20 July.
		Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Total acidity[1]	Not sprayed	14.25	22.5	21.25	35.25	30.50	28.50
	Sprayed	14.20	19.0	22.70	34.50	30.00	28.50
Reducing sugar...	Not sprayed	2.60	2.29	2.05	2.55	4.98	6.17
	Sprayed	2.77	2.28	2.07	2.65	5.56	6.90
Total sugar.....	Not sprayed	2.62	2.31	2.17	2.78	5.29	.....
	Sprayed	2.80	2.30	2.17	2.91	5.80	.....

B. Currants.

		17 May.	30 May.	14 June.	3 July.		
Total acidity.....	Not sprayed	13.5	20.12	34.5	35.5	....	....
	Sprayed	10.5	22.25	38.5	38.5	....	....
Reducing sugar ...	Not sprayed	2.44	2.57	3.24	5.68	....	....
	Sprayed	2.32	2.56	3.50	6.55	....	....
Total sugar	Not sprayed	2.45	2.62	3.55	5.78	....	....
	Sprayed	2.35	2.65	3.83	6.92	....	....

[1] Total acidity is given in terms of number of cc. of normal caustic soda required to neutralize.

Duggar and Cooley (12) used in their experiments castor bean leaves and potted tomato plants and devoted their attention to the effect of Bordeaux mixtures and certain other substances on transpiration. In the work with leaves burette potometers were used and all precautions were taken to eliminate errors due to method; in the case of the potted plants the pots were dipped in paraffin wax and the same sealing mixture was used on the surface of the soil. The pots were provided with a thistle tube for watering and a small bent tube was also inserted to provide for changes in air pressure. The substances used in spraying, or dusting were as follows: 0.96 per cent Bordeaux mixture 1: 1.5, 0.48 per cent Bordeaux mixture 1: 1.5, milk of lime containing 7.92 per cent calcium hydrate, aluminum hydrate, clay as a dust and in water, charcoal, calcium carbonate, and lime-sulphur solution. It will only be necessary for us to consider the effect of the Bordeaux mixtures and milk of lime.

In the potometer work the leaves were sprayed with Bordeaux mixture only, and it was found that spraying increased transpiration whether the leaves were in the open air, or in a room with blinds drawn. In the work with the potted tomatoes, spraying with Bordeaux mixture increased transpiration, but milk of lime gave only a slight and perhaps doubtful increase.

Duggar and Cooley (13) continuing their work on Bordeaux mixture studied the effect of spraying on the rate of transpiration of potted potatoes.

The pots were provided with an auto irrigator of large capacity to obviate the necessity of frequent watering, and much care was taken in the selection of the plants. The plants were sprayed with 1.2 per cent Bordeaux mixture 1: 1.2, 0.6 per cent Bordeaux mixture 1: 1.2, milk of lime containing 7.92 per cent calcium hydrate, lime-sulphur solution diluted 1 to 25, Bordeaux mixtures of the strengths above given plus 0.5 per cent lamp black, and milk of lime containing 1 per cent lamp black.

As will be gathered from a study of Table VIII, increased transpiration was

TABLE VIII.—*Effect of spraying on the rate of transpiration of potatoes.*

Fungicide used.	First period, May 6–11.			Second period, May 11–15.		
	Ten plants.			Seven plants.		
	Average water loss per plant.	Average green weight per plant.	Water loss per gram green weight.	Average water loss per plant.	Average green weight per plant.	Water loss per gram green weight.
1.2% Bordeaux mixture	526.6	50.3	10.46	463.3	55.0	8.42
0.6% Bordeaux mixture	642.4	60.9	10.54	574.0	61.7	9.30
Milk of lime	584.5	70.7	8.27	613.6	76.3	8.04
Bordeaux mixture plus lamp black	792.1	66.1	11.97	635.0	75.2	8.69
Milk of lime plus lamp black	596.6	58.3	10.20	585.6	66.8	8.78
Lime-sulphur	443.0	62.8	7.06	450.7	70.0	6.44
Witness	413.8	61.0	6.78	433.3	63.1	6.86

produced by spraying except in the case of the lime-sulphur solution, the data for the latter wash showing during the first half of the experiment a slight increase followed by a loss during the second half and an average transpiration for the whole period of the experiment only 0.07 gram per gram green weight less than that of the witnesses.

Lutman (14) found that 1.25 per cent Bordeaux mixture 1: 1 invariably gave an increased yield in the case of potatoes, but in experimenting with beans he was unable to secure conclusive data, and is of the opinion that the benefit derived from the wash is due to the protection afforded the former from tipburn and flee-beetle injury, since when injury from these causes does not occur no material increase in yield is obtained. The author sprayed Green Mountain potatoes with Bordeaux mixtures of different strengths in copper and obtained the following results:

	Yield per plant
0.31 per cent Bordeaux mixture 1: 1	2.12
0.62 " " " " "	2.23
1.25 " " " " "	2.26
Witness	1.68

The effect of Bordeaux mixture on the rate of transpiration was also studied, but the results obtained were inconclusive. The author does not believe that

the stimulatory action of Bordeaux mixture is due to the presence of iron in the wash, since in an experiment with potatoes the following data was obtained:

	Yield per acre bushels
1.25 per cent Bordeaux mixture 1:1	243
1.5 " " " " plus 1 per cent ferrous sulphate	235
A mixture of 1.25 per cent ferrous sulphate and 1.62 per cent calcium hydrate	168
Witness	188

Martin (15) studied the effect of spraying with Bordeaux mixture on the rate of transpiration. In a first series of experiments the author studied the effect of 1.25 per cent Bordeaux mixture 1:1 on the rate of transpiration of sprayed leaves, the leaves being sprayed on both the lower and upper surfaces, and found in all cases that spraying increased transpiration. In these experiments leaves of *Ricinus communis*, *Datura metaloides*, *Phaseolus vulgaris*, *Beta cycla*, *Raphanus sativus*, *Caladium sp.*, *Hibiscus cardinalis*, and *Clerodendron balfouri* were used.

In a second series of experiments Martin grew his plants in glazed pots into which the plants were set as soon as they had reached a convenient size. An auto irrigator was inserted in each pot so as to keep the soil moisture constant, and the surface of the soil was then covered with the Briggs and Shantz wax mixture. The following plants were used: tomato, cabbage, pepper, egg plant, soy bean, and the leaves were sprayed on the upper and lower surfaces except in the case of cabbage, which was sprayed only on the upper surface. Spraying increased the transpiration of all the plants but the cabbage. In the case of the soy beans experiments were also made with barium sulphate and dry powdered copper sulphate, but transpiration was increased only by the latter.

Shrive and Martin (16) studied the relative rate of transpiration of sprayed and non-sprayed tomato plants growing side by side. The leaves on about one-half of the branches of one of these plants were sprayed with 1 per cent Bordeaux mixture 1:1 on both the lower and upper surfaces (plant B), while in the case of the other no leaves were sprayed (plant A). The rate of transpiration was determined by means of standardized cobalt chloride paper following the method of Livingston and Shreve (17). The experiments were carried on during the day time, the data being taken hourly with one exception from 5.00 A.M. to 6.00 P.M. Spraying with Bordeaux mixture was found to increase transpiration.

Duggar and Bonns (18) used in their experiments potted potatoes, tomatoes, marguerites, tobacco, *Cyperus esculenta* and abscised leaves of castor beans. The plants were sprayed with 1 per cent Bordeaux mixture 1:1.5, 1.5 per cent Bordeaux mixture 1.5:1, one-half per cent Bordeaux mixture prepared by diluting the 1 per cent 1:1.5 mixture with an equal volume of milk of lime, and in a few cases other substances were used. Eight plants were used in each experiment, four sprayed and four witnesses. The pots were sealed with paraffin wax as was also the top of the soil, provision being, however, made for watering. After the pots were sealed, the plants were placed on a rotating

table specially constructed for the purpose. When the apparatus was set in motion the individual pots were subjected to translatory and nutatory motions. The experiments with potato, tomato, marguerite and tobacco showed that spraying with Bordeaux mixture increased the rate of transpiration mainly if not entirely during the night, while in the case of *Cyperus* no change occurred, and excised castor bean leaves transpired more than the witnesses both night and day.

Ritzema Bos (19) studied the action of milk of lime and Bordeaux mixture on the potato, beneficial results being secured in both cases which he ascribes to the shading effect of the washes. The plants sprayed with Bordeaux mixture remained green the longest, but did not yield as heavily as those sprayed with milk of lime.

II.

In undertaking in turn a study of the response of plants sprayed with Bordeaux mixture I have given attention exclusively to the effect of the several factors which constitute the environment of a sprayed plant on the response obtained. It will be admitted without question that a plant sprayed with a Bordeaux mixture is as regards the immediate environment differently situated than a non-sprayed plant. Hence, the proposed inquiry may be properly begun by a study of the effect of composition of the wash on the response obtained.

EFFECT OF COMPOSITION OF BORDEAUX MIXTURE ON DRY MATTER FORMED AND TRANSPIRATION PER GRAM DRY MATTER.

The plants used in the experiments described below were tomato Bonny Best, Dwarf Horticultural beans and radish Early Scarlet Globe, and they were grown in glazed pots filled with soil containing water to 70 per cent of saturation.* The plants were sprayed weekly with 1 per cent Bordeaux mixture in which the ratio copper sulphate to quick lime used was 1: 1, 1 per cent Bordeaux mixture in which the ratio copper sulphate to lime was 1: alkalinity, and milk lime containing 1.32 per cent calcium hydroxide.

As will be seen from a consideration of Table IX, spraying with 1 per cent Bordeaux mixture 1: 1 and milk of lime was accompanied by loss of weight in six-sevenths of the experiments. Whenever 1 per cent Bordeaux mixture 1:1 acted as a depressant, milk of lime acted similarly, the magnitude of the effect obtained being usually either greater or less than that produced by the former. Since, however, the magnitude of the difference produced is less than 5 per cent when we consider the mean of all the experiments, no importance can be attached to the fluctuations noticed and the conclusion must obviously be drawn that 1 per cent Bordeaux mixture and milk of lime are identical in their effect on dry matter produced.

The plants sprayed with 1 per cent Bordeaux mixture 1: alk weighed in all cases more than did those sprayed with 1 per cent Bordeaux mixture 1: 1 and in six-sevenths of the experiments more than did the plants sprayed with milk of

* For details regarding procedure followed see page 19.

TABLE IX.—*Effect of spraying with Bordeaux mixtures and milk of lime on dry matter formed and transpiration per gram dry matter.*

Variety used	Dry weight.				Transpiration per gram dry matter.			
	Plants sprayed with			Plants not sprayed.	Plants sprayed with			Plants not sprayed.
	Bordeaux mixture.		Milk of lime.		Bordeaux mixture.		Milk of lime.	
	1: 1.	1: alk.			1: 1.	1: alk.		
	Gms.	Gms.	Gms.	Gms.	Gms.	Gms.	Gms.	Gms.
Radish Early Scarlet Globe	0.74	0.95	0.73	0.66	27.8	25.2	25.2	24.2
	1.97	2.33	1.36	2.74	37.5	27.6	37.9	30.6
	2.67	3.10	2.63	2.92	40.73	32.39	32.02	34.84
Tomato Bonny Best.....	2.42	3.18	2.42	2.95	19.7	9.77	15.15	9.95
	7.59	8.47	8.13	8.43	23.82	21.83	23.81	22.06
Bean Dwarf Horticultural.	3.28	3.41	3.14	3.68	20.2	18.2	17.3	18.7
	3.60	4.76	4.89	5.38	6.52	4.97	5.38	4.78

lime, but when we come to compare their behavior with that of the witness plants the difference shown is not so consistent. In four-sevenths of the experiments we find spraying with Bordeaux mixture 1: alk increasing the dry matter formed, while in three-sevenths of the experiments a loss is registered. When we consider all the experiments we find, however, that the witnesses have a mean weight not 3 per cent greater than that of the sprayed plants, a negligible difference. The conclusion is therefore justified that plants sprayed with 1 per cent Bordeaux mixture 1: alk behave in the elaboration of dry matter like non-sprayed plants.

Let us now study the data given in the table on transpiration per gram dry matter. It will immediately be noticed that spraying with 1 per cent Bordeaux mixture 1: 1 always increased transpiration, while milk of lime produced a like effect in five-sevenths of the experiments only. In one experiment the transpiration of the plants sprayed with the milk of lime was greater than that of the plants sprayed with Bordeaux mixture, but in all the others it was less. The similitude of action of Bordeaux mixture 1: 1 and milk of lime is not, therefore, as marked in the case of the effect on transpiration as is the case when dry matter formed is considered. It would appear that the transpiration per gram dry matter formed is slightly less heavy in the case of plants sprayed with milk of lime than in the case of plants sprayed with 1 per cent Bordeaux mixture 1: 1. Spraying with 1 per cent Bordeaux mixture 1: alk caused increased transpiration in two-sevenths of the experiments, a decrease in five-sevenths, the magnitude of the difference between sprayed and non-sprayed plants being usually small. Taking the experiments as a whole we find that the mean transpiration per gram dry matter of the witnesses is only about 4 per cent greater than that of the plants sprayed with Bordeaux mixture 1: alk, a small and negligible difference. We may safely conclude that spraying with Bordeaux mixture 1: alk does not affect the rate of transpiration per gram dry matter.

The data presented in Table IX show that the physiological effect produced by Bordeaux mixture is not due to the copper present, but depends on the ratio copper sulphate to quicklime employed. Now since, within the limits used, the ratio copper sulphate to lime does not affect the composition of the copper precipitate it follows that a Bordeaux mixture made with an excess of lime should produce a response of the same order that the calcium hydroxide present would. The data show that this is actually the case since 1 per cent Bordeaux mixture 1: 1 has the same physiological effect as 1.32 per cent calcium hydroxide.

EFFECT OF PERCENTAGE WATER IN THE SOIL ON THE RESPONSE OF SPRAYED PLANTS.

a. **Method.** In studying the effect of percentage water in the soil on the response of plants sprayed with 1 per cent Bordeaux mixture 1: 1 five experiments were made with tomato Bonny Best, six with Dwarf Horticultural bean, and six with radish early Scarlet Globe. The plants were grown in glazed pots 15.5 cm. high and 11.5 cm. in diameter with a hole 2.5 cm. in diameter drilled in the bottom over which a flowerpot saucer 7.5 cm. in diameter was inverted. Potting soil was thoroughly air dried, uniformly mixed, and screened. The pots to be filled were placed on a Cenco compacting machine and filled with 1000 grams soil, which was then uniformly compacted. After being filled the pots were placed in a trough of water in which they were allowed to stand immersed almost to the rim. The water entered the pots through the holes in their bottoms and gradually rose to the surface of the soil. As soon as the water appeared on the surface of the soil, the pots were removed, allowed to drain until the water just disappeared from the surface of the soil, when the holes were obturated by means of rubber corks. The pots were then weighed and the amount of water required to saturate each individual pot determined. A difference of not more than 4 per cent between the pot with the highest per cent water saturation and the pot with the lowest was allowed in any one experiment. After the pots had been weighed the corks in their bottoms were removed, and they were allowed to stand and drain until the soil had sufficiently dried. The pots were then divided into 4 or 5 series of equal number. When 4 series of pots were used water was added to the pots of series 1 in quantity sufficient to bring the amount of water in the soil to 80 per cent of saturation; to pots of series 2, water was added to 70 per cent of saturation; to pots of series 3, to 60 per cent; to pots of series 4, to 50 per cent; when 5 series were used a set of pots containing water to 90 per cent of saturation was added. As soon as the soil was ready for planting, seeds were sown several to a pot though, except in the case of one experiment with radish, only one plant was grown per pot. As soon as the plants were large enough the first spraying with Bordeaux mixture 1: 1 was given and then repeated at weekly intervals until the plants were harvested, which generally occurred following the third, or fourth spraying. Forty-eight hours after the last spraying the rate of transpiration of the plants was taken covering a period of 24 hours, or less frequently 48 hours. Before the transpiration experiments were begun the plants were carefully watered,

corks were tightly fitted into the drainage holes of their respective pots and the surface of the soil covered with a vaseline beeswax mixture.

During the course of the experiments thermograph and hygrograph records were taken and the daily mean temperatures and relative humidities were obtained by integrating the curves secured. The light intensity was measured on a Violle actinometer, the readings being taken from 8.00 A.M. to 5.00 P.M. inclusive.

β. **Effect of Spraying on Coloration of Foliage.** It is rather commonly stated in the literature that plants sprayed with Bordeaux mixture are greener than non-sprayed plants. Various explanations have been offered to account for this phenomenon, such as fixation of chlorophyll, owing to absorption of small amounts of copper, though Chuard and Porchet (11) have shown that this explanation cannot be correct since the chlorophyll extract from sprayed and non-sprayed leaves is the same color when the proper precautions are taken to remove all copper adhering to the surface of the sprayed foliage. It should, however, be noted that spraying does not invariably heighten the color of sprayed foliage. In fact, in the experiments I have made, increased coloration as judged by ocular inspection was only noted exceptionally. Increased coloration was observed in the second experiment with beans, the first experiment with tomato, and the fourth experiment with radish.* In the experiment with radish the plants were divided into two groups, one with light green foliage and one with dark green foliage. In the case of the sprayed plants eleven-seventeenths of the total number fall into the dark green group, the remainder into the group with pale green foliage, the plants bearing foliage of the latter type all growing in soil containing water to 80 and 90 per cent saturation. In the case of the witnesses three-fifteenths of the plants had dark green leaves, twelve-fifteenths

TABLE X.—*Effect of the environment on the coloration of the foliage of plants sprayed with 1 per cent Bordeaux mixture 1 : 1.*

Plant used.	Coloration of foliage.	Mean temperature.	Mean humidity.	Mean light intensity.
		° C	per cent.	
Radish Early Scarlet Globe, Exp. 2..	Not changed	21.05	83.03	5.68
" " " " " 3..	" "	20.09	61.91	4.44
" " " " " 4..	Darkened	17.15	73.87	2.88
" " " " " 5..	Not changed	20.01	68.99	4.19
" " " " " 6..	" "	19.53	69.28	4.56
Bean Dwarf Horticultural, Exp. 1...	" "	21.07	58.82	6.71
" " " " 2...	Darkened	17.54	77.12	3.79
" " " " 3...	Not changed	22.09	82.84	4.28
" " " " 4...	" "	19.95	70.17	5.07
" " " " 5...	" "	23.29	80.41	3.39
" " " " 6...	" "	22.14	80.83	5.09
Tomato Bonny Best, Exp. 1.....	Darkened	20.59	64.22	3.07
" " " " 2.....	Not changed	17.40	81.70	4.60
" " " " 3.....	" "	19.74	82.51	5.17
" " " " 4.....	" "	18.48	69.19	3.74
" " " " 5.....	" "	20.34	71.82	5.27

light green foliage, the distribution of the plants bearing dark green foliage being irregular. As will be seen from a consideration of the data presented in Table X, the experiments in which the foliage of sprayed plants became more deeply colored were not carried out under exceptional circumstances. It will

*See Table XI.

be remembered that in the case of the experiment with radish a small number of non-sprayed plants also developed dark green foliage, whence it would seem that one is justified in concluding that the action of Bordeaux mixture, whatever it may be, is only an indirect one.

γ. **Effect of Spraying on Dry Matter Formed.** A glance at Table XI shows that, in general, spraying with 1 per cent Bordeaux mixture 1 : 1 has a deleterious effect on the amount of dry matter formed in the plants studied, the tomato being the most markedly affected. In the case of the tomato and bean the per cent water in the soil has no effect whatever on the result. In the case of the former, in all the percentages used the average gain due to spraying is 16.1 per cent; in the case of the latter the average gain due to spraying is 33.3 per cent, but unlike the tomato the plants in the different percentages of water are irregular in their behavior, the greatest gain being 54.5 per cent at 60 per cent of saturation, the lowest 18.1 per cent at 70 per cent saturation. In the case of the radish we find 66 per cent of the plants growing in 50 per cent saturation giving an increased dry weight as a result of the spraying, while the plants growing in higher percentages of water show a beneficial action in a much smaller number of cases, a maximum of 25 per cent at 90 per cent saturation, a minimum of 11.2 per cent at 80 and 70 per cent saturation.

It is to be noted that the tomato plant is a plant that grows well in moderately dry soil, the bean a plant that thrives in dry soils, while the radish does best in moist soils. It would seem, then, that a greater benefit will accrue from spraying when a plant is growing in too dry a soil than when the soil moisture is near the optimum. Growing plants in soil containing water to 40 per cent of saturation is not satisfactory since the amount of water to be added to the air-dry soil is small and a uniform distribution of it in the soil is far from being attained. When, however, an experiment of this nature is attempted and the tomato and bean are grown in soil containing water to 40 per cent saturation, we find, as a consideration of Table XII will show, that increased weight following spraying occurs in 44.4 per cent of the experiments in the case of the former, and in 28.5 per cent of the experiments in the case of the latter. The response of the bean is of the same order as that obtained when the plants were grown in higher percentages of water; but the tomato, on the other hand, behaves nearly like the radish, growing in soil containing water to 50 per cent saturation. We have, then, evidence that spraying becomes increasingly beneficial as the water in the soil falls below the optimum for growth.

To return for a moment to a consideration of Table XI. It will be seen that light intensity did not affect the response of the plants to spraying even when the light was reduced 20 and 40 per cent, but this need not cause surprise since shading to the extent mentioned did not materially affect the growth of the plants as measured by the dry weight formed. Nevertheless, shading had an appreciable effect upon the plants, as will be seen from the data presented in Table XIII. The plants growing in shade were not as stocky as those growing in full light. Obviously but one conclusion can be drawn from these facts. The Bordeaux mixture applied passed more than 80 per cent of the incident light since, had it absorbed or reflected as much as 20 per cent, the plants would have shown an unmistakable response.

TABLE XI.—*Effect of spraying with Bordeaux mixture on the dry matter formed by tomato, bean and radish plants growing in soil containing different percentages of water.*

A. Tomato Bonny Best.

Experiment No.	Light intensity.	Per cent water in the soil.									
		90		80		70		60		50	
		Dry weight of plant.		Dry weight of plant.		Dry weight of plant.		Dry weight of plant.		Dry weight of plant.	
		Sprayed.	Not sprayed.	Sprayed.	Not sprayed.	Sprayed.	Not sprayed.	Sprayed.	Not sprayed.	Sprayed.	Not sprayed.
		Gms.	Gms.	Gms.	Gms.	Gms.	Gms.	Gms.	Gms.	Gms.	Gms.
1	3.07	....	....	2.05	2.71	2.10	2.30	1.53	1.91	1.54	1.70
2	4.60	....	....	4.30	4.07	2.82	3.03	1.87	2.25	1.55	1.66
	3.68	....	....	3.52	4.08	3.12	3.44	1.04	2.27	0.99	2.17
	2.76	....	....	2.52	3.71	1.98	1.90	1.55	1.51	0.96	1.50
3	5.17	....	....	2.37	2.85	1.98	2.16	1.43	1.42	0.15	0.22
	4.13	....	....	2.17	2.28	2.63	2.74	1.65	2.25	0.68	0.91
	3.10	....	....	2.50	2.89	2.07	2.63	2.35	1.56	1.07	1.06
4	3.74	....	....	3.45	4.24	3.12	3.96	2.35	2.60	2.23	2.25
5	5.27	....	....	9.55	10.80	8.92	10.36	8.08	9.19	6.02	7.26

B. Bean Dwarf Horticultural.

1	6.71	....	....	2.48	2.95	2.26	2.59	1.65	1.52	1.40	1.47
	5.36	....	....	3.03	3.05	3.05	3.08	2.38	2.55	1.52	2.15
	4.02	....	....	2.73	2.85	2.50	2.72	2.42	2.38	1.70	1.98
2	3.79	....	....	2.55	2.82	2.45	2.86	2.52	2.97	1.31	1.61
	3.03	....	....	2.65	1.97	2.10	1.83	1.72	1.70	1.54	1.43
3	4.28	....	....	2.66	3.73	4.09	4.36	2.97	3.24	1.46	1.41
4	5.07	....	....	2.95	2.58	3.46	3.43	3.23	2.71	2.40	2.67
	3.04	....	....	3.65	3.30	2.72	3.67	2.52	3.07	2.00	2.54
5	3.39	....	....	4.18	4.20	4.28	4.35	3.29	3.07	3.47	2.80
6	5.09	....	....	2.16	3.17	1.97	2.21	1.53	1.93	....	....
	3.05	....	....	1.85	3.24	1.50	3.10	1.56	2.49	....	....

C. Radish Early Scarlet Globe.

2	5.68	1.03	1.75	1.54	2.47	1.61	2.06	1.54	1.15	1.33	1.07
	4.54	0.65	1.49	0.95	2.31	0.89	1.93	1.22	1.56	1.00	1.45
	3.40	0.87	1.40	0.90	1.99	1.05	1.75	1.08	2.18	0.99	1.45
3	4.44	0.87	0.62	1.14	1.06	1.15	1.39	1.05	0.99	1.19	1.14
4	2.88	0.43	0.55	0.75	0.93	0.74	0.78	0.74	0.75	0.67	0.56
5	4.19	....	....	1.95	3.24	1.97	2.74	1.55	1.81	1.63	1.77
6	4.56	1.05	1.05	0.91	1.30	1.32	1.26	0.90	1.04	0.76	0.74
	3.64	0.56	0.60	0.75	0.75	0.61	0.42	0.43	0.54	0.48	0.40
	2.73	0.50	0.35	0.54	0.65	0.40	0.43	0.39	0.62	0.43	0.35

TABLE XII.—*Effect of spraying on the dry weight of tomato and bean plants growing in dry soil.*

Variety of plant.	Dry weight of plants.	
	Sprayed.	Not sprayed.
	Gms.	Gms.
Tomato Bonny Best	1.66	1.74
	0.46	0.43
	1.54	1.08
	0.40	0.39
	0.26	0.30
	0.88	0.61
	0.79	0.86
	2.24	2.48
	4.02	4.91
Bean Dwarf Horticultural	0.79	0.57
	0.73	1.14
	1.90	2.30
	2.16	1.91
	1.44	1.47
	1.49	1.66
	0.85	0.97

δ. **Effect of Spraying on Rate of Transpiration.** We found in studying the effect of spraying on dry matter produced that the tomato was most deleteriously affected, the dry weight of the non-sprayed plants being higher in 83.9 per cent of the cases, the radish followed next in order with the non-sprayed plants heaviest in 72.7 per cent of the cases, and the beans last with the non-sprayed plants weighing more than the sprayed plants in 66.7 per cent of the cases. The evidence was conclusive that spraying with 1 per cent Bordeaux mixture 1:1 causes loss of weight. When we come to consider the effect of spraying on transpiration per gram dry matter we find, as will be seen from a consideration of Table XIV, that the transpiration is increased in 94.5 per cent of the cases when tomato is used, in 68.9 per cent of the cases when radish is employed, and in 64.3 per cent of the cases when the plant studied is the bean. When transpiration per gram dry matter is considered the plants fall into the same relative position as when dry weight is the criterion employed. Again, as was the case when dry weights were considered, the degree of illumination is without noticeable effect.

ε. **Effect of Soil Fertility on Dry Matter Formed.** In this experiment plants of tomato Bonny Best were used, and they were grown in the pots already described containing 1500 grams very fine acid washed quartz sand, to which the following nutritive elements in solution were added:

	Series A. Gram	Series B. Gram
Calcium nitrate	0.015	0.15
Magnesium sulphate	0.0125	0.125
Calcium acid phosphate	0.006	0.06
Sodium chloride	0.00125	0.0125
Potassium sulphate	0.01625	0.1625
Ferric tartrate	0.00075	0.0075

TABLE XIII.—*Effect of shade and of shade and spraying on the growth in height of Tomato Bonny Best and Dwarf Horticultural Bean.*

Variety of plant used.	Number times sprayed.	Per cent water in soil.	Height. Plants growing in full light.		Height. Plants growing in 80 per cent light.		Height. Plants growing in 60 per cent light.	
			Not sprayed.	Sprayed.	Not sprayed.	Sprayed.	Not sprayed.	Sprayed.
			mm.	mm.	mm.	mm.	mm.	mm.
Tomato	3*	80	240.0	260.0	295.0	270.0	.....	.....
	3*	..	181.0	178.0	198.0	193.0	247.0	222.0
	3	70	200.0	205.0	268.0	247.0	.....	.....
	3	..	159.0	176.0	193.0	191.0	196.0	191.0
	3	60	185.0	175.0	210.0	235.0	.....	.....
	3	..	112.0	140.0	110.0	181.0	165.0	184.0
	3	50	155.0	157.0	195.0	145.0	.....	.....
	3	..	96.0	65.0	87.0	106.0	131.0	131.0
Bean	3*	80	400.0	385.0	627.0	668.0	.....	.....
	3	70	386.0	380.0	460.0	521.0	.....	.....
	3	60	360.0	330.0	380.0	426.0	.....	.....
	3	50	217.0	190.0	287.0	225.0	.....	.....

* Third spraying given two days before measurements were taken.

TABLE XIV.—*Effect of spraying with Bordeaux mixture on the transpiration per gram dry matter formed by tomato, bean, and radish plants growing in soil containing different percentages of water.*

A. Tomato Bonny Best.

Experiment No.	Intensity of light.	Per cent water in the soil.									
		90		80		70		60		50	
		Dry weight of plant.		Dry weight of plant.		Dry weight of plant.		Dry weight of plant.		Dry weight of plant.	
		Sprayed.	Not sprayed.	Sprayed.	Not sprayed.	Sprayed.	Not sprayed.	Sprayed.	Not sprayed.	Sprayed.	Not sprayed.
		Gms.	Gms.	Gms.	Gms.	Gms.	Gms.	Gms.	Gms.	Gms.	Gms.
1	3.07	....	....	28.0	16.2	31.4	23.0	29.0	20.9	16.7	12.7
2	4.60	....	....	43.1	40.5	41.1	38.7	47.5	43.1	42.3	36.5
	3.68	....	....	43.3	35.7	45.2	39.5	46.5	43.1	44.9	31.5
	2.76	....	....	51.0	36.7	48.5	44.9	46.6	43.0	41.1	26.6
3	5.17	....	....	47.3	40.7	44.4	44.2	48.7	45.0	53.5	45.4
	4.13	....	....	48.4	48.3	40.0	38.4	34.8	39.0	47.8	43.9
	3.10	....	....	42.1	38.2	38.4	33.4	39.6	35.6	39.6	38.5
4	3.74	....	....	23.39	18.48	26.51	18.65	32.17	30.28	28.2	26.1
5	5.27	....	....	17.42	14.29	16.03	12.84	14.46	12.82	14.5	11.3

B. Bean Dwarf Horticultural.

1	6.71	....	....	38.8	27.6	32.8	24.2	34.6	34.0	33.2	27.8
	5.36	....	....	32.0	31.2	28.8	28.4	27.9	29.1	27.8	27.6
	4.02	....	....	31.0	29.8	29.3	29.6	25.8	29.2	27.9	28.5
2	3.79	....	....	31.5	32.8	33.2	27.6	27.4	25.4	25.2	24.3
	3.03	....	....	29.0	27.6	27.6	25.8	27.2	24.0	25.4	22.3
3	4.28	....	....	23.2	19.8	19.3	18.3	14.1	20.3	13.2	21.8
4	5.07	....	....	14.6	16.8	12.3	14.4	12.8	9.2	11.2	10.1
	3.04	....	....	10.7	10.8	12.4	7.9	10.9	9.4	11.1	10.0
5	3.39	....	....	21.0	23.9	21.1	23.0	24.8	23.4	21.9	22.3
6	5.09	....	....	14.7	15.9	17.2	20.5	18.0	13.7	....	....
	3.05	....	....	24.0	22.3	26.1	14.6	25.0	22.0	....	....

C. Radish Early Scarlet Globe.

3	4.42	29.2	29.8	29.2	25.7	32.3	29.9	30.4	22.8	29.8	22.8
4	2.88	34.9	25.4	24.8	21.9	27.8	21.5	24.2	17.5	21.1	18.9
5	4.19	....	....	33.4	26.8	36.5	30.7	33.9	29.0	24.0	30.8
6	4.56	19.7	21.8	26.4	23.7	22.8	20.7	32.0	27.9	39.2	26.5
	3.64	38.5	33.3	27.9	32.0	30.0	39.2	43.7	37.0	33.5	39.8
	2.73	36.5	45.5	29.7	30.4	38.7	37.3	38.3	37.9	33.7	43.3

Within each series the plants were grown in sand containing water to 80, 70, 60 and 50 per cent saturation.

Forty-three days after the seeds were planted the experiment was begun.

One-half of the plants in each series was sprayed with 1 per cent Bordeaux mixture 1:1 when the experiment was begun, again after intervals of 13 days and 20 days respectively. The conditions under which the plants were grown may be considered satisfactory, since the mean light intensity was 5.92, the mean temperature 20.8° C., and the mean relative humidity 58.7 per cent.

The data presented in Table XV shows that the effect of the Bordeaux mix-

TABLE XV.—*Effect of soil fertility on response of tomato plants to spraying with 1 per cent Bordeaux mixture 1:1.*

Treatment of plants.	Series A.			Series B.	
	Number of plants.	Soil moisture in per cent saturation.	Mean dry weight.	Soil moisture in per cent saturation.	Mean dry weight.
			Gms.		Gms.
Sprayed	3	80	0.248	80	0.981
Not sprayed	3		0.186		1.036
Sprayed	4	70	0.200	70	0.945
Not sprayed	3		0.232		1.050
Sprayed	3	60	0.128	60	0.614
Not sprayed	2		0.139		0.725
Sprayed	2	50	0.113	50	0.669
Not sprayed	2		0.113		0.780

ture on the plants was virtually the same whether they grew in rich or poor sand. The dry weight of the non-sprayed plants in series B in all cases was heavier, but in the case of series A we find that spraying caused a gain in weight in the case of the plants growing in sand containing water to 80 per cent saturation, while in the case of the plants growing in the driest sand, the weight of both sprayed and non-sprayed plants is equal.

ζ. **Effect of Spraying on Transpiration Per Gram Dry Matter.** At the close of the experiment described in the previous section the rate of transpiration of the plants was taken over a period of 48 hours beginning the second day following the last spraying. The data secured are given in Table XVI. It will be immediately noted that the transpiration of the sprayed plants in both series A and B was always greater than that of the witness plants. The data further show that the transpiration of the sprayed and non-sprayed plants in fertile sand is less than that of similar plants growing under the same soil moisture conditions in less fertile sand. This is in agreement with the well-known fact that plants growing in fertile soils require less water per gram dry matter formed than do plants growing in poor soils.

The experiments detailed in the previous pages show that plants sprayed with 1 per cent Bordeaux mixture 1:1 and with milk of lime containing 1.32

TABLE XVI.—*Effect of soil fertility on transpiration per gram dry matter of tomato plants.*

Treatment of plants.	Soil moisture per cent saturation.	Transpiration per gram dry matter.	
		Series A.	Series B.
		Gms.	Gms.
Sprayed	80	51.92	40.21
Non-Sprayed		38.18	29.77
Sprayed	70	52.41	38.19
Non-sprayed		44.14	28.94
Sprayed	60	61.77	34.92
Non-sprayed		49.99	34.80
Sprayed	50	44.19	34.80
Non-sprayed		39.83	23.55

per cent calcium hydroxide loose weight and transpire more per gram dry matter formed than non-sprayed plants, while 1 per cent Bordeaux mixture 1: alk does not have any deleterious effect whatsoever. The increased transpiration following spraying with 1 per cent Bordeaux mixture 1: 1 occurs irrespective of light intensity and soil fertility. The per cent of water in the soil, on the other hand, has a modifying influence, sprayed plants growing in too dry a soil being less deleteriously affected by Bordeaux mixture 1: 1 than plants growing under more favorable conditions as regards soil moisture. The studies we have so far made tell us how sprayed plants behave, but they do not tell us what is the actual effect of spraying with a Bordeaux mixture, or milk of lime. Do the effects that have been noted immediately follow the application of the mixture to the surface of the leaf, or must the plant actually grow for a period after spraying in order for the conditions noted to develop? Certainly in order for spraying to cause a loss of weight a period of growth of some duration must follow the application of the mixture, but is it actually necessary for a period of growth of some duration to intervene in order for transpiration to be increased? I shall attempt to answer this question.

EFFECT OF SPRAYING WITH BORDEAUX MIXTURES AND MILK OF LIME ON THE RATE OF TRANSPIRATION IMMEDIATELY FOLLOWING THEIR APPLICATION.

We have seen that plants sprayed with Bordeaux mixture 1: 1 and milk of lime transpire more per gram dry matter formed than do non-sprayed plants, but this does not mean that an application of these washes actually modifies the rate of transpiration. Shrive and Martin (16) have presented data showing that spraying actually increases the rate of transpiration of tomato plants during the day while Duggar and Bonns (18) find that the increase occurs during the night.

In my experiments I have always used plants growing in soil with a moisture content of 70 per cent of saturation and assumed that two or more plants maintained in the same positions during a period of 48 hours would respond in

like manner to changes in the environment, and that, in consequence, the transpiration ratios would remain nearly constant, even under rather trying conditions, such as a period favorable to transpiration being succeeded by a period unfavorable, that is, that the plants would be equally responsive to changes in the environment. While in theory greater accuracy would be secured if the plants compared had the same foliage expansion and rate of transpiration, the practical difficulties involved made it desirable to determine whether or not a degree of accuracy sufficient could not be obtained by using plants of the same age but without regard to identity as regards height or vigor. The data presented in Table XVII show that it is not necessary that the transpiration rate of the plants be approximately the same in order to obtain a degree of accuracy sufficient for the purpose at hand, that is, a ratio difference between two periods that does not exceed 20 per cent, and in none of the experiments to be recorded was this difference ever exceeded, so that increased transpiration of a sprayed plant is indicated whenever the difference in rate between the first and second period is in excess of 20 per cent, and *e converso*, for it is perfectly possible for transpiration to increase following spraying if the basis of estimate is dry matter formed, while if the basis were transpiration per unit area no change would be detected. Spraying could reduce photosynthetic activity without affecting the transpiration rate. In the experiments undertaken to test the effect of spraying on the rate of transpiration, I have used 1 per cent Bordeaux mixture 1: 1; 1 per cent Bordeaux mixture 1: 0.2., and milk of lime containing 1.32 per cent calcium hydrate. The precaution was taken in running the experiments to have the hours of opening and closing of the periods as nearly as possible the same. The foliage of the plants was sprayed at the end of the first period and the second period was begun as soon as it was dry. Since the plants had to be watered more or less frequently during the periods depending on the rate of transpiration, the further precaution was taken to water them at the same hours during the second period that they were watered in the first. The data given in the tables are the mean ratios for the individual determinations within a period together with the totals for the day and night periods and the entire period before and after spraying. The percentage difference between the ratios obtained before and after spraying have also been added so as to bring out more clearly the magnitude of the response obtained.

In spraying plants with a fungicide, the foliage is wetted and a certain time must elapse before it dries. I thought that possibly wetting the foliage might have a disturbing effect on the rate of transpiration, but the data presented in Table XVIII show that this is not the case. In the case of the sunflower the upper surface of the leaves was sprayed, but in the case of the castor bean both the upper and lower surfaces were wetted. Any change in rate of transpiration following spraying may therefore be safely ascribed to the substance under experiment.

a. **Experiments with 1 Per Cent Bordeaux Mixture 1 : 1.** A study of the data presented in Table XIX shows that when the entire 24-hour period is considered, spraying has no effect on the rate of transpiration, and the same is true when the day period alone is considered, but when one comes to study the data for the

TABLE XVII.—*Rate of transpiration of plants over two successive periods of time.*

Plant used.	Length of periods.	Plant 1.	Plant 2.	Plant 3.	Plant 4.	Ratios.	Ratio difference.
		Gms.	Gms.	Gms.	Gms.		Per cent
Sunflower	1st period 22½ hrs.	31.5	34.5	30.5	34.0	2/1 1.095; 3/1 0.968; 4/1 1.079	+1.004; +3.30; +4.45
	2nd " 26 9/10 hrs.	23.5	26.0	23.5	26.5	2/1 1.106; 3/1 1.000; 4/1 1.127	
Potato	1st " 20 hrs.	75.0	72.5	74.5	75.0	2/1 0.966; 3/1 0.993; 4/1 1.000	−0.93; +3.53; +1.4
	2nd " 20 "	35.0	33.5	36.0	35.5	2/1 0.957; 3/1 1.028; 4/1 1.014	
Tomato	1st " 26 6/10 "	26.0	34.5	....	....	1/2 0.753	+1.46
	2nd " 23½ "	19.5	25.5	....	....	1/2 0.764	
Horticultural bean	1st " 23½ "	40.5	20.0	....	....	1/2 2.025	−12.8
	2nd " 23 "	11.5	6.5	....	....	1/2 1.769	
Castor bean	1st " 20 "	87.0	76.5	93.5	....	2/1 0.879; 3/1 1.074	+12.8; −2.78
	2nd " 19 3/4 "	68.0	67.5	71.0	....	2/1 0.992; 3/1 1.044	
Coleus golden bedder	1st " 23½ "	135.5	146.5	112.5	....	2/1 1.081; 3/1 0.830	−3.2; +17.4
	2nd " 23½ "	183.5	192.0	179.0	....	2/1 1.046; 3/1 0.975	
Coleus verschafftei	1st " 24 "	60.5	68.5	....	....	2/1 1.132	−10.5
	2nd " 19½ "	112.0	113.5	....	....	2/1 1.013	

TABLE XVIII.—*Effect of spraying leaves of castor bean and sunflower with water on the rate of transpiration of these plants.*

Plant used.	Periods.		Ratio $\frac{\text{Sprayed plants.}}{\text{Non-sprayed plants.}}$	Ratio difference
	Begun.	Ended.		
				Per cent.
Castor bean	1st 10-4: 1.30 P.M.	1st 11-4: 9.30 A.M.	0.897	+1.2
	2nd 11-4: 1.15 P.M.	2nd 12-4: 9.00 A.M.	0.908	
Sunflower	1st 21-1: 1.28 P.M.	1st 22-1: 10.10 A.M.	1.280	+5.4
	2nd 22-1: 2.25 P.M.	2nd 23-1: 10.10 A.M.	1.350	

TABLE XIX.—*Effect of spraying with 1 per cent Bordeaux mixture 1:1 on the rate of transpiration of potato, tomato, Russian sunflower, Coleus golden bedder, and Coleus verschaffelt.*

A. Experiments with potato.

Experiment begun 31-7; ended 2-8.

Ratios taken.	Hours at which data were taken and corresponding mean ratios (Sprayed plants. / Non-sprayed plants.)						Mean ratios (Sprayed plants. / Non-sprayed plants.)		
	12 NOON.	2.30 P.M.	5.30 P.M.	8.30 P.M.	5.00 A.M.	9.00 A.M.	Entire period.	Day period.	Night period.
Before spraying	1.109	1.231	1.221	1.350	1.029	1.096	1.178	1.176	1.029
After spraying	1.194	1.237	1.124	1.288	1.217	1.169	1.169	1.190	1.217
Per cent difference	+7.6	+0.5	−7.9	−4.6	+18.2	+6.6	+1.5	+1.2	+18.3

Experiment begun 22-7; ended 24-7.

	5.30 P.M.	8.30 P.M.	4.45 P.M.	9.00 A.M.	11.30 A.M.				
Before spraying	1.333	1.539	1.145	1.380	1.360	.....	1.217	1.221	1.145
After spraying	1.416	1.808	1.366	1.612	1.300	.....	1.227	1.265	1.366
Per cent difference	+6.2	+17.5	+19.3	+16.8	−4.4	.....	+0.8	+3.6	+19.3

Experiment begun 7-8; ended 9-8.

	5.30 P.M.	8.00 P.M.	5.00 A.M.	9.00 A.M.	11.30 A.M.				
Before spraying	0.965	0.962	0.930	0.950	0.973	.....	0.962	0.965	0.930
After spraying	1.000	0.969	1.055	0.882	1.096	.....	1.014	1.010	1.055
Per cent difference	+3.6	+0.7	+13.4	−7.1	+12.6	.....	+5.4	+4.6	+13.4

Experiment begun 15-3; ended 17-3.

	5.35 A.M.	9.30 A.M.	1.30 P.M.	5.00 P.M.	7.20 P.M.				
Before spraying.....	0.736	0.867	0.798	0.798	0.800	.....	0.805	0.807	0.736
After spraying.....	1.117	0.769	0.721	0.776	0.857	.....	0.754	0.744	1.117
Per cent difference....	+51.7	−11.3	−9.6	−2.7	+7.1	.....	−6.3	−7.8	+51.7

Experiment begun 21-3; ended 23-3.

	4.00 P.M.	7.15 P.M.	5.45 A.M.	9.00 A.M.	12.45 P.M.				
Before spraying.....	1.140	1.083	1.166	0.969	1.212	.....	1.070	1.068	1.166
After spraying.....	1.118	1.045	1.375	0.954	0.921	.....	1.065	1.052	1.375
Per cent difference....	−1.9	−3.5	+17.9	−1.5	−24.0	.....	−0.5	−1.5	+17.9

B. Experiments with tomato.

Experiment begun 12-3; ended 14-3.

	2.00 P.M.	7.00 P.M.	11.00 P.M.	5.45 A.M.	9.45 A.M.				
Before spraying.....	1.068	0.836	0.800	0.800	0.893	.....	0.962	1.000	0.842
After spraying.....	0.872	0.902	1.851	1.370	0.783	.....	0.876	0.886	1.467
Per cent difference....	−18.3	+7.9	+131.3	+71.2	−12.3	.....	−8.9	−11.4	+74.2

Experiment begun 20-3; ended 22-3.

	1.30 P.M.	6.30 P.M.	11.00 P.M.	5.30 A.M.	10.00 A.M.				
Before spraying.....	0.989	1.066	1.395	1.222	1.018	.....	1.028	1.012	1.277
After spraying.....	0.961	1.230	4.339	3.800	1.088	.....	1.245	1.072	4.023
Per cent difference....	−2.8	+15.4	+211.0	+210.6	+6.8	.....	+21.1	+5.9	+215.0

TABLE XIX.—*Continued.*

C. Experiments with Russian sunflower.

Experiment begun 15-3; ended 17-3.

Ratios taken.	Hours at which data were taken and corresponding mean ratios — Sprayed plants. / Non-sprayed plants.						Mean ratios — Sprayed plants. / Non-sprayed plants.		
	2.00 P.M.	6.30 P.M.	11.00 P.M.	5.30 A.M.	10.00 A.M.		Entire period.	Day period.	Night period.
Before spraying	1.066	1.086	0.641	0.737	1.114	.....	1.024	1.076	0.702
After spraying	1.071	1.103	1.206	1.230	1.041	.....	1.099	1.069	1.223
Per cent difference	+0.5	+1.5	+88.1	+66.8	−6.5	.....	+7.3	−0.6	+73.2

Experiment begun 24-3; ended 26-3.

	6.30 P.M.	11.00 P.M.	5.30 A.M.	10.00 A.M.					
Before spraying	1.030	0.975	1.000	0.947	.....	.....	0.939	0.991	0.986
After spraying	1.134	1.529	1.857	0.961	.....	.....	1.140	1.072	1.677
Per cent difference	+10.09	+56.9	+85.7	+1.5	.....	.....	+21.4	+8.1	+70.0

Experiment begun 19-9; ended 21-9.

	1.40 P.M.	7.00 P.M.	6.00 A.M.	9.30 A.M.					
Before spraying	0.982	0.955	0.970	0.900	.....	.....	0.968	0.969	0.970
After spraying	0.803	0.840	0.923	1.000	.....	.....	0.843	0.793	0.923
Per cent difference	−18.2	−12.0	−4.8	+11.1	.....	.....	−12.9	−18.1	−4.8

Experiment begun 24-3; ended 26-3.

	1.30 P.M.	5.00 P.M.	7.30 P.M.	5.25 A.M.	9.35 A.M.				
Before spraying.....	1.165	1.148	0.962	1.035	1.142	.....	1.147	1.151	1.035
After spraying.....	1.080	1.167	1.162	1.222	1.013	.....	1.121	1.108	1.222
Per cent difference....	−7.3	+1.6	+20.7	+18.0	−11.2	.....	−2.2	−3.7	+18.07

Experiment begun 15-3; ended 17-3.

	5.00 P.M.	7.25 P.M.	5.40 A.M.	9.35 A.M.	1.40 P.M.				
Before spraying.....	1.111	1.119	1.012	1.205	1.195	.....	1.158	1.168	1.012
After spraying.....	1.125	1.016	1.697	1.170	1.156	.....	1.161	1.148	1.697
Per cent difference....	+1.2	−9.2	+67.7	−2.9	−3.2	.....	+0.2	−1.7	+67.7

Experiment begun 9-3; ended 11-3.

	7.00 P.M.	5.40 A.M.	10.00 A.M.						
Before spraying.....	0.961	1.277	0.935	.....	.....	.....	0.966	0.932	1.277
After spraying.....	0.943	2.000	.953	.....	.....	.....	1.038	0.949	2.000
Per cent difference....	−1.8	+56.6	+1.92	.....	.....	.....	+7.4	+1.8	+56.6

Experiment begun 21-3; ended 23-3.

	4.15 P.M.	7.30 P.M.	5.40 A.M.	9.05 A.M.	12.30 P.M.				
Before spraying.....	1.036	1.184	0.909	1.089	1.049	.....	1.064	1.066	0.909
After spraying.....	1.123	1.373	1.290	1.061	1.037	.....	1.093	1.088	1.290
Per cent difference....	+8.4	+15.9	+41.9	−2.5	−1.1	.....	+2.7	+2.06	+41.9

TABLE XIX.—*Continued.*

D. Coleus golden bedder.

Experiment begun 19-7; ended 20-7.

Ratios taken.	Hours at which data were taken and corresponding mean ratios — Sprayed plants. / Non-sprayed plants.						Mean ratios — Sprayed plants. / Non-sprayed plants.		
	2.30 P.M.	5.30 P.M.	9.00 P.M.	4.30 A.M.			Entire period.	Day period.	Night period.
Before spraying	0.994	0.953	1.230	1.263	.....	.....	1.002	0.990	1.263
After spraying	1.023	1.057	1.147	1.050	.....	.....	1.035	1.034	1.050
Per cent difference	+2.9	+10.9	−6.7	−16.8	.....	.....	+3.2	+4.5	−16.8

Experiment begun 12-7; ended 14-7.

	3.00 P.M.	9.00 P.M.	5.00 A.M.	10.00 A.M.					
Before spraying	1.224	1.102	0.981	1.037	.....	.....	1.141	1.142	0.981
After spraying	1.229	0.823	1.290	0.985	.....	.....	0.912	0.903	1.290
Per cent difference	+0.4	−25.3	+31.4	−5.0	.....	.....	−20.0	−20.9	+31.4

Experiment begun 25-7; ended 27-7.

	3.00 P.M.	9.00 P.M.	5.00 A.M.	10.00 A.M.					
Before spraying	1.130	1.239	0.865	1.181	.....	.....	1.243	1.254	0.865
After spraying	0.954	1.454	1.175	0.964	.....	.....	1.001	0.997	1.175
Per cent difference	−15.5	+17.3	+35.8	−18.3	.....	.....	−19.4	−20.5	+35.8

Experiment begun 30-8; ended 1-9.

	1.10 P.M.	5.45 P.M.	8.10 P.M.	6.00 A.M.	10.00 A.M.				
Before spraying.....	0.852	1.013	0.850	0.888	0.984	.....	0.891	0.892	0.888
After spraying.....	0.845	0.796	1.200	1.046	0.964	.....	0.874	0.862	1.046
Per cent difference....	−0.8	−21.4	+41.1	+17.7	−2.0	.....	−1.9	−3.3	+17.7

E. Coleus vershafftei.

Experiment begun 12-7; ended 14-7.

	3.00 P.M.	9.00 P.M.	5.00 A.M.	10.00 A.M.					
Before spraying.....	0.753	0.829	0.900	0.928	.....	.....	0.892	0.795	0.900
After spraying.....	0.592	1.020	1.666	0.850	.....	.....	0.737	0.727	1.666
Per cent difference....	−21.3	+23.0	+85.1	−8.4	.....	.....	−17.3	−8.5	+85.1

Experiment begun 25-7; ended 27-7.

	3.00 P.M.	9.00 P.M.	10.00 A.M.						
Before spraying.....	1.008	1.061	1.000	1.080	.....	.....	1.031	1.031	1.000
After spraying.....	0.873	1.500	1.294	0.943	.....	.....	0.932	0.925	1.294
Per cent difference....	−13.3	+41.3	+29.4	−12.6	.....	.....	−9.6	−10.2	+29.4

Experiment begun 30-8; ended 1-9.

	1.00 P.M.	5.36 P.M.	8.00 P.M.	5.45 A.M.	9.40 A.M.				
Before spraying.....	1.113	1.128	0.625	1.157	1.100	.....	1.100	1.096	1.157
After spraying.....	1.071	0.926	1.571	1.714	1.097	.....	1.059	1.027	1.714
Per cent difference....	−3.7	−17.8	+151.3	+48.1	−0.3	.....	−3.7	−6.3	+48.1

night period he finds that there may or may not be an increase in the rate of transpiration of the sprayed plants. For instance, in the case of the five experiments with potatoes increased transpiration occurred at night only in one instance; in the case of the tomato increased transpiration always occurred; in the case of the sunflower increased transpiration was obtained in five of the seven experiments performed; in the case of the Coleus Golden Bedder increased transpiration was recorded in 50 per cent of the experiments, and in the case of the Coleus verschafftei in all the experiments. It will be noticed that, whenever the data were taken twice during the night interval, in three-fourths of the experiments the greater increase was recorded during the first period.

β. **Experiments with 1 Per Cent Bordeaux Mixture 1: 0.2.** A study of the data presented in Table XX shows that plants sprayed with Bordeaux mixture 1: 0.2 behave in a similar manner to plants sprayed with 1: 1 mixture when subjected to the same environmental conditions though the increased transpiration obtained is not as large. It will be remembered that when we studied the effect of Bordeaux mixture 1: 1 on the rate of transpiration per gram dry matter formed (see ante page 18) we found that 1 per cent Bordeaux mixture 1: 1 did not affect the plant in the same way as 1 per cent Bordeaux mixture 1: alk (=1: 02 for all intents and purposes). In the case of the former, transpiration was greater than that of the witnesses, while in the case of the latter the sprayed and non-sprayed plants did not materially differ in behavior.

γ. **Experiments with Milk of Lime.** In the experiments the data for which are presented in Table XXI the milk of lime was made so as to contain 1.32 per cent calcium hydroxide. It will be noticed that milk of lime has the same effect on the relative transpiration as the Bordeaux mixtures used, though the intensity of the response obtained is more nearly like that produced by 1 per cent Bordeaux mixture 1: 1. In all the experiments in which milk of lime was used under the same environmental conditions as the 1: 1 mixture, a like effect on the rate of transpiration was obtained except in the case of the experiments of the 24th of March and the 15th of March on sunflower, when the milk of lime caused respectively a doubtful increase and no increase at all.

EFFECT OF SPRAYING THE UNDER SURFACE OF LEAVES ON THE RATE OF TRANSPIRATION.

We have been considering the effect on rate of transpiration of spraying the upper surfaces of leaves. The question may now be asked: What effect, if any, does spraying the under surface of leaves have? The data presented in Table XXII indicate that spraying the under surface of leaves affects the rate of transpiration in the same manner as spraying the upper surface.

III.

We have now to consider the cause of the effects produced by spraying. In the first place we will note that plants sprayed with 1 per cent Bordeaux mixture 1: 0.2 behave more nearly like non-sprayed plants than do those sprayed with 1 per cent Bordeaux mixture 1: 1 and milk of lime when dry matter and

transpiration per gram dry matter are considered, but that the two types of Bordeaux mixture and milk of lime affect the plant in a similar manner when the transpiration rate over a period of 24 hours is considered. There can be no question, of course, but that the Bordeaux mixtures and milk of lime cast a shadow. From the results of the experiments performed we would expect milk of lime and Bordeaux mixture 1:1 to cast obvious shadows of about equal intensity, but that Bordeaux mixture 1:0.2 would be quite transparent to luminous radiations, and the following figures confirm in part this view.

			Per cent light transmitted.
Bordeaux mixture 1:0.2*	2.13	Grms. Cu. per spr. meter	63.4
*Bordeaux mixture 1: alk	2.13	" " " " "	39.0
Bordeaux mixture 1:1	2.13	" " " " "	11.6
Milk of lime	8.52	" CaO " " "	25.4

The data above given show that Bordeaux mixture 1 : 0.2 transmits 1.62 times more light than Bordeaux mixture 1 : alk; the 1 : alk wash 1.53 times more than milk of lime; and milk of lime 2.2 times more light than Bordeaux mixture 1 : 1. Milk of lime and Bordeaux mixture 1 : 1 affect plants in a very similar manner, much more nearly alike than their transparency to luminous radiations would indicate. But the radiations received by plants in daylight are not all luminous. Hence, when we consider luminous radiations only we are measuring but part of the total energy received. Let us, therefore, study the transparency of Bordeaux mixtures and milk of lime to the whole spectrum. In performing the experiment to be described I have used a 10-couple thermopile, sensitive galvanometer, and a Nernst lamp as the source of radiation. The thermopile was enclosed in a box in one of the walls of which a small circular opening was cut facing the lamp and adapted to hold a quartz plate. In making an experiment the quartz plate was covered with three drops of the mixture to be tested and dried. After the mixture had dried and the plate had come to room temperature it was placed before the thermopile and the lamp was lit, the voltage of the current being controlled in the usual way. A double pole switch was inserted in the line between the thermopile and the galvanometer, and readings were taken alternately to the left and the right of the scale in order to eliminate error due to zeroshift. After a set of readings had been taken the plate was removed, dipped in dilute hydrochloric acid, washed, dried, and the radiation transmitted determined as before. The difference between the first and second set of readings gave a measure of the athermancy of the mixture.

An example of the data obtained is given in Table XXIII.

When the spectrum as a whole is considered, Bordeaux mixture 1 : 1 and milk of lime are about equally transparent, and much more opaque than Bordeaux mixture 1 : alk, and there is concordance between the physical properties of the washes and the response of plants sprayed with them.

If one sprays thoroughly bean leaves with Bordeaux mixture 1:1 he will no-

* Bordeaux mixture 1: alk is a little less transparent than Bordeaux mixture 1: 0.2 but the differences are not so large but that one can without material error consider the effects produced by these mixtures as identical.

TABLE XX.—*Effect of spraying with 1 per cent Bordeaux mixture 1: 0.2 on the rate of transpiration of potato, tomato, and Russian sunflower,*

A. Experiments with potato.

Experiment begun 7-8; ended 9-8.

Ratios taken.	Hours at which data were taken and corresponding mean ratios — Sprayed plants. / Non-sprayed plants.					Mean ratios — Sprayed plants. / Non-sprayed plants.		
	5.30 P.M.	8.00 P.M.	5.00 A.M.	9.00 A.M.	11.30 A.M.	Entire period.	Day period.	Night period.
Before spraying	1.025	1.125	1.144	0.975	1.028	1.037	1.082	1.144
After spraying	1.088	1.483	1.115	0.857	1.142	1.128	1.083	1.115
Per cent difference	+6.1	+31.8	−2.5	−12.1	+11.1	+8.7	+0.0	−2.5

B. Experiments with tomato.

Experiment begun 12-3; ended 14-3.

	2.00 P.M.	7.00 P.M.	11.00 P.M.	5.45 A.M.	9.45 A.M.			
Before spraying	1.074	0.872	0.800	1.066	1.000	1.017	1.024	0.909
After spraying	0.957	0.830	1.481	1.048	0.919	0.937	1.008	1.141
Per cent difference	−10.8	−4.8	+85.1	−1.7	−8.1	−7.8	−1.5	+25.5

Experiment begun 20-3; ended 22-3.

	1.30 P.M.	6.30 P.M.	11.00 P.M.	5.30 A.M.	10.00 A.M.			
Before spraying	1.060	1.066	1.046	1.000	1.072	1.062	1.065	1.015
After spraying	1.092	0.906	1.415	1.333	1.088	1.048	1.028	1.367
Per cent difference	+3.0	−15.0	+35.2	+33.3	+1.5	−1.3	−3.4	+34.6

C. Experiments with Russian sunflower.

Experiment begun 15-3; ended 17-3.

	2.00 P.M.	6.30 P.M.	11.00 P.M.	5.30 A.M.	10.00 A.M.			
Before spraying	0.997	0.802	0.641	0.897	0.933	0.912	0.936	0.808
After spraying	0.967	0.962	1.120	1.115	0.925	0.984	0.948	1.117
Per cent difference	−3.0	+19.9	+74.7	+24.3	−0.8	+7.9	+1.3	+38.2

Experiment begun 24-3; ended 26-3.

	6.30 P.M.	11.00 P.M.	5.30 A.M.	10.00 A.M.				
Before spraying	0.813	0.975	1.071	0.905	.....	0.873	0.860	1.019
After spraying	0.910	1.176	1.428	0.910	.....	0.954	0.912	1.290
Per cent difference	+11.9	+20.6	+33.2	+0.5	.....	+9.3	+6.0	+26.6

Experiment begun 9-3; ended 11-3.

	7.00 P.M.	5.40 A.M.	10.00 A.M.					
Before spraying	0.898	0.993	0.941	.....	.....	0.893	0.884	0.993
After spraying	0.930	1.300	0.893	.....	.....	0.955	0.923	1.300
Per cent difference	+3.5	+30.9	−5.1	.....	.....	+6.9	+4.4	+30.9

TABLE XXI.—*Effect of spraying with milk of lime containing 1.32 per cent calcium hydroxide on the rate of transpiration of potato, tomato, Russian sunflower, Coleus golden bedder, and Coleus verschaffelei.*

A. Experiments with potato.

Experiment begun 7-8; ended 9-8.

Ratios taken.	Hours at which data were taken and corresponding mean ratios — Sprayed plants. / Non-sprayed plants.					Mean ratios — Sprayed plants. / Non-sprayed plants.		
	5.30 P.M.	8.00 P.M.	5.00 A.M.	9.00 A.M.	11.30 A.M.	Entire period.	Day period.	Night period.
Before spraying	0.940	0.937	1.162	0.926	0.983	0.962	0.953	1.162
After spraying	0.852	1.186	1.052	0.571	1.047	0.942	0.875	1.052
Per cent difference	−9.3	+26.5	−9.4	−38.3	+6.5	−2.1	−8.2	−9.4

B. Experiments with tomato.

Experiment begun 12-3; ended 14-3.

	12.00 NOON.	7.00 P.M.	11.00 P.M.	5.45 A.M.	9.45 A.M.			
Before spraying	0.908	0.654	0.600	0.800	0.861	0.845	0.856	0.681
After spraying	0.768	0.920	3.333	2.338	0.817	0.881	0.803	2.554
Per cent difference	−15.4	+40.6	+455.5	+192.2	−5.1	+4.2	−6.2	+275.0

Experiment begun 20-3; ended 22-3.

	1.30 P.M.	6.30 P.M.	11.00 P.M.	5.30 A.M.	10.00 A.M.			
Before spraying	1.140	0.960	1.046	0.888	1.079	1.080	1.089	0.925
After spraying	1.019	1.143	2.169	2.066	0.966	1.114	1.052	2.109
Per cent difference	−1.0	+19.0	+107.4	+132.6	−10.5	+3.1	−3.4	+128.0

Experiment begun 15-3; ended 17-3. C. Experiments with Russian sunflower.

	2.00 P.M.	6.30 P.M.	11.00 P.M.	5.30 A.M.	10.00 A.M.			
Before spraying	1.100	1.172	0.961	0.865	1.084	0.968	0.980	0.893
After spraying	0.982	1.032	0.862	1.115	0.995	1.005	0.997	1.037
Per cent difference	−10.7	−11.9	−10.3	+28.9	−8.2	+3.8	+1.7	+16.1

Experiment begun 24-3; ended 26-3.

	6.30 P.M.	11.00 P.M.	5.30 A.M.	10.00 A.M.				
Before spraying	1.048	0.792	0.785	1.100	.....	1.050	1.074	0.789
After spraying	0.993	0.941	1.000	1.098	.....	1.024	1.031	0.967
Per cent difference	−5.2	+18.8	+27.5	−0.1	.....	−2.4	−4.0	+22.5

Experiment begun 9-3; ended 11-3.

	5.50 A.M.	10.15 A.M.	7.15 P.M.					
Before spraying	0.609	0.896	0.769	.....	.....	0.757	0.770	0.609
After spraying	0.850	0.867	0.883	.....	.....	0.851	0.851	0.850
Per cent difference	+39.5	−3.2	+14.8	.....	.....	+12.4	+10.5	+39.5

Experiment begun 30-8; ended 1-9. D. Experiments with Coleus golden bedder.

	1.10 P.M.	5.45 P.M.	8.10 P.M.	6.00 A.M.	10.00 A.M.			
Before spraying	0.887	0.947	0.850	1.222	0.984	0.931	0.905	1.222
After spraying	1.000	0.941	1.057	1.162	1.059	1.000	0.989	1.162
Per cent difference	+12.7	−0.6	+24.3	−4.9	+7.6	+7.4	+9.3	−4.9

Experiment begun 12-7; ended 14-7. E. Experiments with Coleus verschafftei.

	3.00 P.M.	9.00 P.M.	5.00 A.M.	10.00 A.M.				
Before spraying	0.992	1.042	1.000	1.142	.....	1.023	1.024	1.000
After spraying	0.904	0.903	1.666	0.958	.....	0.930	0.918	1.666
Per cent difference	−8.8	−13.3	+66.6	−16.1	.....	−9.0	−10.3	+66.6

TABLE XXII.—*Effect of spraying lower surface of leaves with 1 per cent Bordeaux mixture 1: 1 on the rate of transpiration of potato and Russian sunflower.*

A. Experiments with potato.

Experiment begun 21-3; ended 23-3.

Ratios taken.	Hours at which data were taken and corresponding mean ratios					Mean ratios Sprayed plants. / Non-sprayed plants.		
	4.00 P.M.	7.15 P.M.	5.45 P.M.	9.00 A.M.	12.45 P.M.	Entire period.	Day period.	Night period.
Before spraying	0.812	0.583	0.666	0.597	0.801	0.748	0.749	0.666
After spraying	0.990	1.000	1.000	0.727	0.697	0.781	0.787	1.000
Per cent difference	+21.9	+71.5	+50.1	+21.7	−12.9	+4.4	+5.0	+50.1

B. Experiments with Russian sunflower.

Experiment begun 21-3; ended 23-3.

	4.15 P.M.	7.30 P.M.	5.40 A.M.	9.05 A.M.	12.30 P.M.			
Before spraying	0.988	0.973	1.090	0.976	1.056	1.017	1.015	1.090
After spraying	1.050	1.522	1.483	0.888	1.052	1.067	1.056	1.483
Per cent difference	+6.2	+5.6	+36.0	−9.0	−0.3	+4.9	+4.0	+36.0

Experiment begun 24-3; ended 26-3.

	1.30 P.M.	5.00 P.M.	7.30 P.M.	5.25 A.M.	9.35 A.M.			
Before spraying	1.397	1.098	0.888	1.214	1.170	1.274	1.270	1.214
After spraying	1.326	1.381	1.906	1.777	1.216	1.414	1.360	1.777
Per cent difference	−5.0	+25.7	+114.6	+46.3	+3.7	+10.9	+7.0	+46.3

Experiment begun 15-3; ended 17-3.

	5.00 P.M.	7.25 P.M.	5.40 A.M.	9.35 A.M.	1.40 P.M.			
Before spraying	1.125	1.052	0.826	1.031	1.101	1.076	1.096	0.826
After spraying	1.054	1.000	1.344	0.937	1.138	1.097	1.079	1.344
Per cent difference	−6.3	−4.9	+62.7	−9.1	+3.3	+1.9	−1.5	+62.7

TABLE XXIII.—*Amount of radiation transmitted by 2 per cent Bordeaux mixture 1 : 1, 2 per cent Bordeaux mixture 1 : 1 : 0.2, 2 per cent Bordeaux mixture 1 : alk, and milk of lime containing 2.64 per cent calcium hydroxide.*

Deflection of galvanometer.

Plate.				Plate.				Plate.				Plate.			
Coated with milk of lime.		Clear.		Coated Bordeaux mixture 1 : 1.		Clear.		Coated Bordeaux mixture 1 : alk.		Clear.		Coated Bordeaux mixture 1 : 0.2		Clear.	
Cm.	Cm	Cm.	Cm.	Cm.	Cm.	Cm.	Cm.	Cm.	Cm.	Cm.	Cm.	Cm.	Cm.	Cm.	Cm.
4.9	7.3	15.1	16.4	5.15	7.7	14.7	16.2	9.3	10.9	14.6	15.95	15.8	11.0	21.5	17.0
4.8	7.2	15.1	16.3	5.00	7.6	15.0	16.3	9.2	10.7	14.6	15.80	15.6	10.9	21.5	17.1
4.8	7.2	15.1	16.4	5.00	7.5	14.9	16.5	9.4	10.7	14.5	15.80	15.6	11.1	21.7	17.2

Radiation transmitted by milk of lime 35.2 per cent
" " " Bordeaux mixture 1 : 1 40.6 " "
" " " " " 1: alk 62.8 " "
" " " " " 1 : 0.2 68.9 " "

TABLE XXIII.—*Effect of night temperature on the transpiration of plants sprayed with 1 per cent Bordeaux mixture 1: 1.*

Plant used.	Transpiration ratio. Sprayed-plants: Non-sprayed plants, 2nd period.	Temperature. Greenhouse minimum.	Temperature. Open air* minimum.
		°C.	°C.
Potato	+18.3	22.0	+23.9
	+19.3	19.0	+21.1
	+13.4	19.0	+18.3
	+51.7	15.0	0
	+17.9	5.0	+1.6
Tomato	+74.2	15.5	—11.1
	+215.0	15.0	— 2.7
Sunflower	+73.2	15.5	— 6.6
	+70.0	15.0	— 3.9
	—4.8	16.5	+ 8.3
	+41.9	5.0	+ 1.6
	+67.7	14.4	0
	+56.6	11.6	— 2.7
	+18.07	7.0	+ 5.5

*Weather Bureau record. Thermometer shelter on the roof of a neighboring building.

tice that they will not assume the paraheliotopic position as rapidly as non-sprayed leaves. We are also commonly told that sprayed plants, even in the absence of parasitic diseases, remain longer green than non-sprayed plants. Edgerton (20) has pointed out that the fruit of sprayed tomatoes is slower ripening than that on non-sprayed plants, and in spraying experiments carried on in recent years for the control of leaf spot of tomato (*Septoria lycopersici*) we have the fact of delayed maturation mentioned (21). Again, in the case of the potato and the grapevine, authors are in agreement that sprayed plants remain green longer than non-sprayed plants; in other words maturation is delayed. As is well known, plants grown in shade mature less rapidly than plants grown in full sunlight. Bordeaux mixture 1: 1 casts an obvious shadow, and plants sprayed with it remain longer green than non-sprayed plants, that is, they behave in all respects like shaded plants. A plant sprayed with Bordeaux mixture is a shaded plant. The question may be asked, Does not the quality of the light transmitted by the Bordeaux mixture have an effect on the response of the plant and is not the effect produced more than one of simple shade? Spectrograms of Bordeaux mixtures containing various ratios copper sulphate to lime have been made, but none of the mixtures were found to possess selective absorption either in the visible spectrum or ultra-violet light, that is, between the end of the visible at wave length 400 millimicrons and 300 the limit beyond which all sunlight is absorbed by the air.* Hence the quality of the light received by the leaf plays no part in the effect produced.

We have now to consider the cause of the increased transpiration which sometimes occurs in sprayed leaves at night. It will be remembered that 1 per cent

*I wish to thank Dr. Theodore Lyman, Harvard University, who very kindly had these determinations made for me in his laboratory.

Bordeaux mixture 1:1 and milk of lime have a deleterious effect on growth, while 1 per cent Bordeaux mixture 1: alk is neutral in action, but we also found that under certain conditions at night both types of Bordeaux mixture and milk of lime affected the sprayed plants in a similar manner. The fact that we have to explain is, therefore, How can 1 per cent Bordeaux mixture 1:1, 1 per cent Bordeaux mixture 1:0.2, and milk of lime similarly affect a leaf and at the same time differ in their effect on growth response? The first thought that will enter one's mind is that the solution to the problem is to be found in the study of the effect of these substances on heat radiation. I shall attempt to show that this assumption satisfactorily explains the facts observed.

The leaves of plants radiate energetically and therefore cool rapidly. In nature radiation is frequently intense enough to cause a deposit of dew on the surface of leaves of low-growing plants exposed to the sky; but leaves may cool sufficiently even to a height above the ground of more than six feet to become covered on both the upper and lower surfaces with dew.

Also it must not be forgotten that at night respiration tends to maintain the body temperature of the leaf slightly above that of the immediate environment, hence radiation into the immediate environment occurs as well as into space. Therefore, even under conditions unfavorable for radiation into space, loss of heat by radiation into the immediate environment will occur and will be the more marked the greater the differences in temperature between it and the leaf. The rate of transpiration of a leaf at night will depend, therefore, on the degree of radiation into space and the immediate environment, and consequently any treatment of a leaf that will reduce radiation will maintain it at a higher temperature and augment transpiration.

We are told that plants sprayed with Bordeaux mixture resist white frost better than non-sprayed plants, which means nothing more, of course, than that sprayed leaves do not cool as readily as non-sprayed leaves; and we have seen that under certain circumstances sprayed plants transpire more than non-sprayed plants, while at the other times transpiration is not noticeably affected. Are these differences at all related to conditions favorable or unfavorable to transpiration? The experiments I have performed were carried out in a greenhouse and therefore the plants did not at any time radiate into space as energetically as would plants freely exposed owing to the athermancy of ordinary glass to the infra-red. Nevertheless, the data presented in Table XXIII indicate that transpiration is increased under conditions favorable for radiation. Furthermore it will be remembered that in those experiments in which data were taken twice during the night, the greatest difference in transpiration ratios was recorded at the first observation, which is in harmony with the above explanation. The evidence so far adduced is, however, only circumstantial. It remains to be shown that Bordeaux mixtures and milk of lime are athermous to infra-red radiations. In studying the transmission of radiation by Bordeaux mixtures and milk of lime I have used a 10-couple thermopile, sensitive galvanometer and Nernst lamp, set up as previously described together with a Baly's absorption tube containing a saturated solution of iodine in carbon bisulphide placed in front of the lamp to cut off luminous radiation. The data obtained is summarized in Table XXIV.

TABLE XXIV. *Transmission of infra-red radiation by Bordeaux mixtures and milk of lime.*

Mixture used.	Radiation transmitted.
	Per cent
None	100
Bordeaux mixture 1 : 0.2	57.50
Bordeaux mixture 1 : alk	35.20
Bordeaux mixture 1 : 1	29.10
Milk of lime	50.20

A consideration of the data presented in the table shows that the Bordeaux mixtures and milk of lime are relatively opaque to the infra-red. Bordeaux mixture 1 : alk and Bordeaux mixture 1 : 1 especially showing a high degree of athermancy.

These results are in harmony with the experimental data I have obtained with plants, as will be seen from a consideration of Table XXV. When transpira-

TABLE XXV.— *Effect of spraying with 1 per cent Bordeaux mixture 1: 1, 1 per cent Bordeaux mixture 1: 0.2, and milk of lime on the rate of transpiration of tomato and sunflower plants*

Plant used.	Transpiration ratio $\frac{\text{Sprayed plants.}}{\text{Non-sprayed plants.}}$ 2nd period.		
	Plants sprayed with		
	Bordeaux mixture 1: 1.	Bordeaux mixture 1: 0.2	Milk of lime.
Tomato	70.0 215.0	25.5 34.6	275 128
Sunflower	73.2 70.0 56.6	38.2 26.6 30.9	....

tion is increased at night all three mixtures cause an increase. A greater increase is obtained when the plants are sprayed with 1 per cent Bordeaux mixture 1: 1 than when they are sprayed with 1 per cent Bordeaux mixture 1: 0.2, but milk of lime which the data presented in Table XXIV indicate should produce a response more nearly like Bordeaux mixture 1: 0.2, sometimes caused increased transpiration of the same order as the 1: 1 Bordeaux mixture. No great consequence can, however, attach to this irregularity.

The experiments described in the previous pages lead but to one conclusion: the action of Bordeaux mixtures on plants is one of shade, not shade in the sense

Schrander used the term but shade in the sense of opaqueness to the spectrum as a whole.

We have seen that when a Bordeaux mixture is quite transparent to incident radiation, as for instance a 1 : 0.2 or 1 : alk mixture, no response is obtained, but that when more opaque mixtures are used, such as a 1 : 1 mixture or milk of lime wash, vegetation is slightly depressed. Evidence was also advanced which tended to show that when a plant grew in too dry a soil there was a tendency for a Bordeaux mixture that would otherwise have proved a depressant to become beneficial; and this is obviously an effect of shade, for shading is beneficial to plants growing in too dry a soil.

Increased transpiration due to spraying never occurred during the day, and of course should not occur if the effect produced is one of shade.

We also found that the degree of athermancy of Bordeaux mixtures to the infra-red affected the rate of transpiration of plants at night, and that this effect was more marked under favorable conditions for radiation.

The magnitude of the physiological response caused by a Bordeaux mixture on plants depends, therefore, entirely on the degree of opaqueness of the wash to the spectrum as a whole, speaking broadly to the intensity of the shadow cast.

IV.

We have seen that Bordeaux mixture 1: 1, Bordeaux mixture 1: 0.2, and milk of lime reduce rediation, while Bordeaux mixture 1: 1 and milk of lime also cast an obvious shadow. From these facts we may draw certain practical conclusions:

When shading is injurious to plants that have to be sprayed a Bordeaux mixture containing only a small amount of lime should be used. It would, however, not be proper to use a mixture containing a ratio copper sulphate to lime of 1: 0.2 or 1: alk, since it has been shown that such mixtures are not as adhesive as washes containing a larger proportionate amount of lime. A Bordeaux mixture 1: 0.5 is more adhesive than mixtures containing relatively larger or smaller amounts of lime and should therefore be given the preference when shading is objectionable. When shading is desired then a 1: 1 Bordeaux mixture should be employed if protection from parasitic endophytes is required, and milk of lime whenever a substance without fungicidal properties is utilizable.

SUMMARY.

I. The magnitude of the physiological response produced by a Bordeaux mixture on plants depends on the degree of opaqueness of the wash to the spectrum as a whole, speaking broadly to the intensity of the shadow cast.

II. The composition of Bordeaux mixture has a marked effect on the response of the sprayed plant. A Bordeaux mixture transparent to the spectrum permits a plant to grow in all respects like a non-sprayed plant, but milk of lime and opaque Bordeaux mixtures cause decrease in dry matter formed and increased transpiration.

III. Bordeaux mixtures and milk of lime are opaque to radiations of long wave length. Therefore, under conditions favorable for radiation, sprayed plants cool less rapidly than non-sprayed plants and thus transpire more freely.

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